V. 3

127

THE GEOLOGICAL

AND

NATURAL HISTORY SURVEY

OF MINNESOTA.

The Twentieth Annual Report, for the Year 1891

N. H. WINCHELL,

State Geologist.

MINNEAPOLIS:

HARRISON & SMITH, PRINTERS.

1893.

THE GEOLOGICAL

AND

NATURAL HISTORY SURVEY

OF MINNESOTA.

The Twentieth Annual Report, for the Year 1891.

N. H. WINCHELL,

State Geologist.

MINNEAPOLIS:
HARRISON & SMITH, PRINTERS.
1893.

THE GEOLOGICAL

AND

NATURAL HISTORY SURVEY

OF MINNESOTA.

The Twentieth Annual Report, for the Year 1891.

N. H. WINCHELL,

State Geologist.

MINNEAPOLIS:
HARRISON & SMITH, PRINTERS.
1893.

Pres. Emery,

THE BOARD OF REGENTS

OF THE

UNIVERSITY OF MINNESOTA.

Hon. Greenleaf Clark, St. Paul,	1892
Hon. Cushman K. Davis, St. Paul	1892
Hon. Knute Nelson, Alexandria,	1896
Hon. John S. Pillsbury, Minneapolis,	1896
Hon. H. H. Sibley, St Paul,*	1897
Hon. Ozora P. Stearns, Duluth,	1897
Hon. William Liggett, Benson,	1897
Hon. Stephen Mahoney, Minneapolis,	1895
Hon. S. M. Emery, Lake City,	1895
Hon. Wm. R. Merriam, St. Paul. Governor	*ex officio.*
Hon. David L. Kiehle, St. Paul, Superintendent of Public Instruction,	*ex officio.*
Dr. Cyrus Northrop, Minneapolis, President of the University.	*ex officio.*

OFFICERS OF THE BOARD.

Hon. J. S. Pillsbury,	*President.*
Hon. David L. Kiehle,	*Recording Secretary.*
Pres. Cyrus Northrop,	*Corresponding Secretary.*
Hon. O. C. Merriman,	*Treasurer.*

* Deceased Feb. 18, 1891.

ERRATA.

On page 10, after the footnote add *A. Irving, Metamorphism of Rocks, page 96.*

On page 16, 16th line from top, for "structure of crystallines rocks" read structures of crystalline rocks.

On page 17, under "Remarks," eighth line from the top, for "No. 1" read No. 4.

On page 68, fourth and eighth lines from the bottom, for "539" read 538.

On page 88, last line, before "T. 66-5" insert 22.

On page 138, sixth line from top, strike out "V."

On page 184, line 6 from top, after "interior" insert *of the continents.*

On page 185, line 17 from bottom, for "Ontario, Erie and Huron," read *Ontario.*

On page 188, line three from top, for "Goulai's," read *Goulais.*

On page 191, line one from top, for "labradorite" read *plagioclase.*

On page 191, line ten from top, for "altitude" read *attitude.*

On page 192, line five from top, for "oragraphic" read *orographic.*

On page 192, line nineteen from bottom, for "material" read *natural.*

On page 193, line twenty from bottom, for "canals" read *vents.*

On page 193, line seventeen from top, for "all" read *mostly.*

On page 194, line seven from top, for "this" read *the.*

On page 196, line fifteen from top, for "impossible" read *possible.*

On page 196, line nineteen from top, omit "protecting."

On page 201, line five from bottom, after "It is not" insert *infrequently.*

On page 202, line one from top, for "indentation" read *indentations.*

On page 203, line nineteen from bottom, for "embankment" read *embayment.*

On page 215, line fifteen from bottom, for "time" read *line.*

On page 216, line sixteen from top, for "Of the two" read *Of two,*

On page 217, in title of Fig. 1, for "Keewenian" read *Keweenian.*

On page 223, line 14 from bottom, for "fallen" read *full.*

On page 226, line eleven from top, for "terraces" read *terranes.*

On page 233, line thirteen from top, omit "[See Pl. X., Fig. 2]."

On page 234, line twenty-one from top, for "plane" read *plan.*

On page 236, line three from bottom, for "aerial" read *a real.*

On page 238, line twenty-two from top, for "in" read *on.*

On page 241, line six from top, for "leads" read *levels.*

On page 242, line nineteen from top, for "XXI." read *XI.*

On page 250, line two from bottom, for "339.7" read *439.7.*

On page 252, line sixteen from bottom, after "cave of the" insert *embayment.*

On page 252, line nine from bottom, for "dents" read *strands.*

On page 253, line four from top, for "thickened" read *thicker.*

On page 270, at bottom of cut, insert "Fig. 11."

On page 271, line three from top, for "build" read *built.*

On page 271, line twenty-one from bottom, for "and gravel" read *gravel.*

On page 273, line twenty from top, for "gravel" read *finest.*

On page 277, line thirteen from top, for "rigid" read *ridged.*

On page 281, line eleven from bottom, for "benches" read *beaches.*

On page 284, line fourteen from top, for "altitude" *attitude.*

On page 289, line five, from bottom, for "altitude" read *attitude.*

ADDRESS.

MINNEAPOLIS, May 1, 1892.

To the President of the University:

DEAR SIR.—Herewith is transmitted the twentieth annual report of the Geological and Natural History Survey, of which I have charge. This marks the close of the second decade of my connection with this work, which began with the commencement of the survey in 1872. It is with some satisfaction that I can look over the work of the last twenty years, and with some regret that I can see its deficiencies. As a State enterprise, however, the Minnesota survey is unique in its plan, its supervisory auspices, its slow but uninterrupted progress, and in the duration of its personal directorship.

Ten years ago, in the submission of my tenth annual report, I ventured to congratulate the University and the State on the success which had attended the survey at that date, but the second ten years have been more prosperous than the first ten. Therefore, while renewing my congratulations, I think it is safe to bespeak for the third decade as great and, perhaps, greater advance in all the channels of scientific research ordered by the law. The University of Minnesota has a golden opportunity to place herself far in the van of progress in science among such institutions in America, and the overseers of the survey, as they are also overseers of the University, cannot fail to see the ways and means for bringing about such a result.

Respectfully submitted,

N. H. WINCHELL,

State Geologist and Curator of the General Museum.

CONTENTS.

REPORT.

SUMMARY STATEMENT. The funds of the survey, derived almost wholly hitherto from sales of the Salt Spring lands, not only became exhausted, on account of increased expense of exploration in the northern part of the state, but indebted to the University fund proper for advances to the amount of about fifteen thousand dollars. The Legislature of 1887 made a cash appropriation, of ten thousand dollars for certain economic researches, and that with some aid from the Salt Spring fund kept the field work going for four years, i. e. till the report on the iron ores of the state (Bulletin No. VI.) was published. The Legislature of 1891 made another cash appropriation for the survey amounting to fifteen thousand dollars, with a view of cancelling, in part at least, the deficit in the funds and of carrying forward the field-work toward completion. In the meantime the iron ore interests have rapidly developed, and it has become incumbent on the survey to make much closer examination into the geographic distribution of the rocks carrying this ore, as well as into many questions relating to their geology. While it has been purposed to enter at once on the preparation of the final report on the geology of the northern part of the state, it is found to be judicious to prosecute further field-work there. Large public and private interests are involved in the developments taking place. It would be discreditable to stop the survey short of satisfactory completion while such important economic results are dependent on a knowledge of the rocks carrying this iron ore. The season has been spent therefore in further field examinations and especially on the Mesabi iron range. Mr. U. S. Grant was at work on the eastern end of the range, and his (accompanying) report shows some of the results of his field-work. Mr. H. V. Winchell was directed to make a general economic study of the entire range, and to carry his data and statistics to as late a date as possible. His report therefore owing to lateness of publication laps over into the year 1892. The same season

(1891) Dr. A. C. Lawson, late of the Canadian geological survey, was employed to make a survey of the elevated beaches of the north shore of lake Superior, and incidental to that to make such study of the rock formations as his opportunities afforded. His interesting report on the beaches accompanies this, and two other supplementary papers by him are to be included in a separate publication—probably Bulletin IX.

Renewed activity also has been given to paleontological work on the Trenton and Hudson River fossils. Mr. Chas. Schuchert made a collecting tour in Wisconsin and in Iowa, and in southern Minnesota, and was engaged to assist in the preparation of chapters for the Paleontology of the state, while Mr. E. O. Ulrich continued his work on the Bryozoa. In all the paleontological work the survey has been aided gratuitously by Mr. W. H. Scofield, of Cannon Falls. The printing of Vol. III, of the final report, as outlined in the "Summary statement" for the seventeenth annual report, is now going forward.

It was thought best to divide the report of Mr. Herrick on the Mammals of the state into two parts, and to issue them separately as bulletins (VII and VIII). The first part, embracing the popular and semi-technical descriptions, is now in press, and when issued will constitute an interesting publication of the survey. The other portion is in Prof. Herrick's hands, and when it has been revised by him, and changed so as to comport with the advances made since the volume was first tendered for publication, it will appear as another bulletin of the survey. The report of Dr. Hatch on the Birds of the state is intended for similar publication, but it is not at hand. Dr. Hatch left the state about a year ago and has never actually put his manuscript in the custody of the survey. His present address is unknown.

Since the last summary statement the nineteenth report has been issued and distributed. The library of the survey gradually grows. Our reports are sent in exchange to all parts of the world. The list of additions by this means shows this growth. There is also herewith presented a statement of registrations in the museum, now reaching 8,441.

I.

THE CRYSTALLINE ROCKS,

Some Preliminary Considerations as to their Structures and Origin.

N. H. WINCHELL.

Sufficient field-work has now been done on the crystalline rocks of the state to enable us to enumerate the formations which they contain, and to express with some confidence the stratigraphic relations which they bear to one another. These important preliminary steps, having been taken with care and thoroughness, there remains the task to deduce from the facts ascertained some further principles of taxonomic geology and of genetic derivation for the rocks themselves.

In attempting to present these facts of the geology of the lake Superior region in such a manner as to indicate some general truths which may serve as guides for classification and nomenclature, it is the desire of the writer to acknowledge that he has been but one among several recent factors that have helped to bring some system out of confusion and chaos. After the report of Foster and Whitney in 1851, on the mineral lands of the lake Superior region, in which it was maintained that it was impossible to divide the crystalline rocks into any systematic, consistent order of succession, either stratigraphic or chronological, there have been numerous geologists who, having made examinations in one part or another of the lake Superior region, have shown that the crystalline rocks are susceptible of stratigraphic subdivision, and have attempted to express such subdivision. Generally they have shown that it is possible to separate them into two parts. This binary classification was really instituted prior to the work of Foster and Whitney by Alexander Murray and Sir William Logan of the Canadian survey. While the Canadian

survey itself has tenaciously held to this simple classification, some of its individual members have, unwittingly sometimes, but intentionally at other times, put on record important facts that have called attention to inconsistencies, and to the confusion that has resulted, and some of them have in a measure abandoned the original nomenclature of Murray and Logan, and have instituted new names to express subdivisions that are needed and which were not recognized by Murray and Logan.

On the other side of lake Superior, the state surveys of Michigan and Wisconsin, while adding many and interesting facts to the general fund of knowledge of the crystalline rocks, have added but little to the advancement of their special taxonomy, or their genetic relationships. These surveys were mainly occupied with the discovery of their geographic areas, and the delineation of their local details of stratigraphy and outcrop. They adopted, in general, the stratigraphic principles and the nomenclature of the Canadian survey of 1857, but also showed that it was necessary to institute many minor distinctions in stratigraphy—without, however, attempting to establish any certain order for all the distinctions which they recorded.

It is evident that before any inquiry can be entered upon as to the more minute internal relations of these formations, it is essential that the serial order which thay sustain to each other, at least some of their grand stratigraphic taxonomy, shall be determined. To the solution of these problems very much time has been given, both by members of the United States geological survey, and by those engaged on some of the state surveys. An essential concord has been reached by the more recent investigators on some of the main questions of relationship, as well as some of the minor stratigraphic details. While the statements of this paper will be based on facts developed in Minnesota, it cannot be questioned that the principles involved, and many of the facts on which they are based will be found duplicated with equal or greater clearness, in Wisconsin and Michigan, as well as in Canada. The great synclinorium of the lake Superior valley seems to have been wrought out in a series of strata of very old date, and it manifests its concordant history in the plications and duplications of its rocky rim on all its sides alike.

The principal rock terranes, as made out in the region northwest from lake Superior are as follows :

1. A series of alternating fragmental and eruptive beds, known as Nipigon or Keewenawan, the upper portion composed almost netirely of red sandstones, placed unconformably beneath a later

series of conglomerates and sandstones in which is found the "Dicellocephalus fauna" of the primordial.

2. Lower down are found alternating beds of "eruptive" sheets and fragmental rocks, but the fragmental are quite different from those in No. 1, being thin-bedded slates, often black siliceous and actinolitic schists, magnetitic jaspers, quartzytes and cherty quartzytes. These are interbedded with sheets of eruptive rock or rock composed of pyroclastic materials which were probably of tufaceous origin, presenting more or less evident sedimentary structures.

3. The eruptive facies is intensified at this horizon by the protrusion of immense quantities of true basic eruptive (gabbro) which is found to have embraced in itself considerable masses of the next older strata, particularly of the Pewabic quartzyte and its modifications. This gabbro is intimately associated with acid eruptive rocks of cotemporary date, constituting red felsytes, quartz porphyries and reddish granites. This gabbro is the bearer of large quantities of titanic magnetite, and very often the underlying quartzyte, involved in the gabbro, is also highly charged with magnetite, though never titaniferous.

4. The bottom of the Animikie is characterized by a great quartzyte associated with iron ores and cherts, which, however, do not always appear in their typical characters at this horizon. Associated with this quartzyte, and with some of the beds immediately overlying it, are the important iron deposits of the "Mesabi range." This quartzyte lies unconformably on all the older rocks, but principally it has been examined in its contact with the granite and greenstone of the Giant's range. Wherever its lower beds are found exposed they are apt to be conglomeritic with debris from the underlying formations. This has been styled Pewabic quartzyte. It is subject to great lithologic variations, due on the one hand to admixtures of mechanical debris from the older rocks, and on the other to chemical precipitations in the ocean in which it was gathered, and to the mingling of volcanic tuff from the eruptions that were coincident with its deposition, some of which are seen as interbedded sheets of cotemporary date. Its color is usually gray, but on the Mississippi river, at Pokegama falls, it is superficially red to the depth of two or three inches, and still further southwest, in Pipestone county, it is extensively changed to a red color. Its grains are coarse, rounded and evident, but they are joined, generally, into a compact mass by the deposition of secondary silica. In the near vicinity of the cotemporary volcanic disturbances its grain is very fine, like jaspilyte, and in some cases it has acquired a dense crystalline structure from contact with the gabbro.

There is but little, if any doubt, that the great physical break which separates the preceding from the following extends throughout the lake Superior district, and that it marks the greatest erosion-interval which has been discovered in paleozoic geology, as distinctly pointed out by Dr. A. C. Lawson.

A scant fauna has been found to characterize the terranes down to this point, and so far as the characters indicate, the fauna is primordial. This whole series, by its stratigraphic position, its fauna, lithology, and its accidental features, is bound in one grander group, and resembles that which is known as Taconic.

Nos. 3 and 4 are separable from No. 2 by divergence in dip and strike, as well as by a marked difference of lithology. Between these and No. 2 there is in Minnesota some evidence of nonconformity, and such has also been stated of them in Wisconsin.

5. Below this group is the fundamental "complex," made up of crystalline rocks and their debris. It is in this complex that are found some of the problems that have long been studied, and in which remain some of the unsettled questions. Still great advance has been made in deciphering its structure and stratigraphy. Three grand parts have been made out, in stratigraphic order, while a fourth is well established, but occurs sporadically. The first of these parts is a volcanic formation of great thickness, occupying, however a fixed position in geographic extent and in stratigraphic order. This is known as the Keewatin. Most of its rocks are volcanic tuffs presenting more or less evidence of aqueous sedimentation. There is one important part of this series, specially designated Kawishiwin, which differs from the rest. It embraces the great bulk of the "greenstones" and chloritic schists and jasperoid hematites of the formation, and it seems to be the latest known member of the Keewatin, although it still remains to be shown whether this massive greenstone phase be not of fitful distribution and liable to occur in other parts of the Keewatin. The most of the Keewatin rocks are graywackes, sericitic schists, agglomerates, conglomerates, with some exceedingly fine-grained, glossy, serpentinous schists. It also embraces modifications of these, which will be mentioned later. The conglomerates and the agglomerates appear at different horizons, the latter being especially abundant in the Kawishiwin horizon. The hematite ores which characterize the Keewatin, are found in the Kawishiwin stage. They are in lenticular lodes, and in general they stand upright, conformable with the general position of the rocks and and all the macro-structure of the country.

6. The next older rocks are conformably linked with the Keewatin rocks in stratigraphy, and they are no less intimately united with them lithologically. There is an increasing degree of fresher crystallization evident in the Keewatin toward the bottom, and when the strata become wholly crystalline they have received the name of Vermilion series. There has not yet been seen in Minnesota any unconformity between the Keewatin and the Vermilion, and indeed it appears that the crystalline characters occur sometimes out of their normal stratigraphic place, indicating that their existence is not dependent on stratigraphic order wholly—though in the main it is. The Vermilion schists, otherwise known as crystalline schists, contain magnetic iron ore, but generally they are destitute of it. They are usually plainly stratiform, in as evident a manner as the stratified rocks of the Keewatin, but they also embrace some dark, massive "greenstone" belts in which no stratification bands are visible. They consist essentially of mica schists and hornblende schists.

7. The base of the Vermilion, when not disturbed by upheaval in Archean time, has a gradual transition into conformable, stratiform gneiss, which is of like character with the transition from the Keewatin to the Vermilion. Indeed there is nothing to distinguish the Vermilion schists from the gneiss of the Laurentian, except an increase in the feldspathic and siliceous ingredients at greater depth in the series. Even after the Laurentian characters, viz., more or less massive or gneissic acid rock, have become fully established through a thickness of a hundred, or three hundred feet, there may recur, well within the gneiss, a parallel and extended belt of rock with struction and lithology like those of the Vermilion schists, or, *vice versa*, there have been seen thick beds of gray gneiss, conformable with the sedimentary stratification, well within the Vermilion schists, making an essential part of the series. Therefore it is plain that the base of the Vermilion, when not broken by upheaval and brecciation is an uncertain and vanishing plane which cannot be located exactly with any unanimity or consistency by different field geologists—nor even by the same geologist.

But this normal interstratification and gradual passage from the Vermilion to the Laurentian is not always found, nor indeed is it, perhaps, the most frequent. There is more frequently a great disturbance manifest at this horizon, resulting in brecciation and confusion. In most cases there are numerous "dikes" of the lighter-colored granitic rock cutting the schists, and there are larger areas and knobs ureless basic rock. There is

every character that indicates that these were both in a fluid or plastic state, and that the only non-fluid rock was the older schist which is seen variously embraced in isolated pieces by both.

One other character pertaining to the structural relations of the parts of the Archean complex should be mentioned, viz: The eruptive characters just described, so far as they pertain to the Laurentian gneiss, do not always come into contact with the crystalline schists of the Vermilion, but sometimes small areas of Laurentian granite are directly in contact with schists that have the imperfectly crystalline condition of the Keewatin.

The Archean complex, therefore, is, normally, a unit in its grander features, and while separable into differing members, in the same manner as the overlying Taconic, and liable to disturbance and to the action of invading igneous rock, in the same manner it is plainly one in its grander history and its chief genetic characters.

With this statement, which gives a concensus* of the results reached by several geologists who have given special attention to the field evidences, we have given, perhaps, all that can be said to be settled as to the major structural relations. It is when we go further, and attempt to discover some of the minor relations subsisting between these parts, or enter upon the study of their genesis, that we find a divergence of opinion. These differences of opinion result, of course, from a study of the problems from different points of view, or along different ways of research, by reason of which different geologists have seen only portions of the evidence. It is to be presumed that when two geologists should see and comprehend all the facts there would be between them an exact agreement of opinion. The significance of a geological fact, when once pointed out, can be apprehended and applied only in one of two diverse directions, and can be used by one geologist as well as by another. This, of course, requires that the fact and its interpretation shall be embraced in a correct underlying philosophy. If a philosophical principle be assumed, at the outset, which is false, there will be danger of a vicious interpretation of all the facts that are discussed by the geologist who holds the false philosophy. He may be very expert in the discovery and the grouping of the relations of the facts which he employs, but all his reasoning is vitiated by the weakness, or worthlessness, of his initial datum. It is necessary, therefore, to examine every assumed principle on which

*The position of the principal gabbro horizon (that at Duluth and at Little Saganaga lake) may be excepted from this statement, as it is not settled so as to be admitted by all observers, that the gabbro followed immediately after the Pewabic quartzyte.

this or the other interpretation is based, and to maintain among the facts discussed a rigid and correct rule of relationship within the accepted philosophy. It is equally certain that the correctness or falsity of a philosophical principle applicable to geologic facts, when pointed out, can be apprehended, and would be, by one candid geologist as readily as by another. There is hence, on the assumption that geologists are all candidly in pursuit of the truth only, a reason to expect that not only will all the facts necessary to the solution of present problems be discovered and known finally by all geologists concerned, but that they will be subordinated to a sound philosophical discussion and settlement.

The unsettled problems pertaining to these rocks, whether in the Laurentian, the Ontarian or the Taconic, are very frequently connected with the "eruptive" members, whether truly eruptive or not, and with the genesis of some of the minor non-eruptive parts. It might be mentioned also that there is still some question as to the stratigraphic place of the gabbro of the Mesabi range of hills and as to its relation to the Animikie. There is also some uncertainty as to the manner of distribution of the eruptive rocks both of the Animikie and of the Nipigon through those formations, and the effect of such distribution on the cotemporary sedimentary beds at places remote from the points of issue of the eruptives. In short, it is not altogether certain but that the terms Nipigon and Animikie have been applied to some extent at different and distant points to different but cotemporary phases of the same formation.* The Pewabic quartzyte shares less in this uncertainty, maintaining its identity at the base of the Taconic.

USE OF TERMS.

It is one of the primary essentials to the investigation of the crystalline rocks, after the ascertainment of their physical and stratigraphic characters, that there shall be a clear understanding of the terms selected to define them, and this necessity appears greater in no case than in the use of the terms "metamorphism," and "alteration" and the terms "schistose," "laminated," "stratified," "gneissic," "bedded" and "banded." These terms have been variously employed, and great confusion has resulted.

Anyone who has given attention to the rocks as they appear in the field will have noted that there are two opposing tendencies of change which the Archean rocks have experienced. He finds a force, or several forces, which promote what might be styled a de-

* The Nipigon here is supposed to be the equivalent of the Keweenawan, to which this statement more strictly applies.

structive or degradational transition from one mineral condition to another—in other words a *weathering process*. This has resulted both in past geologic eons and in the short time that has elapsed since the glacial epoch, in converting hornblende to chlorite and to talc or serpentine, biotite to muscovite, and to the various hydrated micas, feldspar to mica or kaolin, menaccanite to leucoxene, and in short, it is that change which is preliminary to the final disintegration of the minerals concerned and their disappearance either in the superficial soils or in solution and distribution in any waters that can carry them away. The forces that promote this change are water and atmospheric air, and since these have been present since the rocks existed as rocks, and were also present and equally or more active at the date of their birth, it is plain that the effect of their influence will be likely to be found throughout the history of the Archean rocks, at all points where there can be said to be any identifiable data to mark their history. It will be noticed that all these changes of condition result from an attack, an ever energetic assault, which the atmosphere, through some of its agents, is making on the primary elementary conditions of the minerals of the earth. It is essentially a carbonizing, an oxygenizing and a hydrating process. It is ever present, and its avenues of effective attack are myriad. As a result of this warfare between the earth and the air the surface of the earth has become habitable by the various grades of organized beings, vegetable and animal. This process is one of the most important, in its progressive steps, and one of the most stupendous in its results, however slow and gentle it appears, which we can contemplate in the history of the earth. It is not designed here to dwell upon it, although it has resulted in the production of all our limestones, sandstones, shales and usual soil-producing strata, and has brought about those conditions by which water at ordinary temperatures can remain permanently on the surface of the earth.

Opposed to this destructive process, the geologist who contemplates the crystalline rocks observes another operation. This force acts to expel the carbon and the water, and as much of the oxygen as possible, which have been taken up by the operation of the destructive process. This is essentially a reconstructive operation, and its effect is to bring all the minerals subjected to its action back again to or toward the conditions which they possessed originally. The reconstructive process will be impeded, naturally, and sometimes diverted from its normal result, by accidents of environment, either physical or chemical, which have transpired since the primary crystallization, through the action of

the destructive agents of the air, already mentioned. For instance, whereas a normal and natural change, through destructive agencies, would be manifested in the conversion of augite to hornblende, and of hornblende to chlorite, and also of an orthoclase feldspar to a potash mica, and thence to sericite, and to kaolin, when the reconstructive process were to take these final products in hand, it would not be able, perhaps, to restore them to their original conditions of composition and crystallization, producing augite and orthoclase feldspar, but the utmost of its results might be a form of hornblende and a black mica. Certain natural and insurmountable obstacles seem to oppose the reformation of exactly the same minerals through that method of regeneration. It cannot be questioned, however, that could the original conditions be restored, both of heat, pressure and moisture, and the same forces be brought to bear on the same elements, in the same proportions, as in the first crystallzation, the result would be the reconstruction of identically the same crystals. This recrystallizing process, compared with that of disintegration, is much less observable, and in the later geological ages it is less common than in the earlier. This apparent diminution, however, may be only apparent, and due to the fact that its later effects are likely to be buried at great depths below the clastic strata of the supercrust, and hence invisible to the geologist. It is only where and when some of the causes that promote it break through the supercrust and become apparent at the surface of the earth, as in the cases of volcanic forces, that the student of these rocks can observe the method of this reconstruction in the production of its characteristic minerals. The causes that produce these retro-changes are, hence, only exceptional and local, and do not disturb in the grand aggregate, the onward course of the unequal warfare between the air and the earth, which inevitably is tending to the subjugation of the latter by the former. The reaction of the crystalline forces against disintegration was most powerful and effective in Archean time, when the earth was heated nearer the surface. The voluminous sedimentation that resulted from the first attacks of the atmospheric agents on the heated earth's surface, has been the most exposed to this re-construction. At that early date in the formation and dissemination of fragmental materials by the air or the ocean, the nature of the sediments themselves had not so far become differentiated from their parent sources, as are the sediments of the present ocean, and in the event of re-construction could more easily and more abundantly re-produce the minerals of the parent rock. The forces which are concerned in the recon-

struction of the primary minerals in the Archean rocks, are seated below the crust of the earth, and their power seems to increase at greater depths. Whenever they manifest themselves in concrete form at or near the surface they are combined, in some occult relations with pressure and moisture. Primarily we may, perhaps as correctly as any way, express these forces in a single term, by the words *dry heat*, either as the result or as the cause of gravitation, but as dry heat was associated with varying degrees of pressure and perhaps of moisture, in the first crystallizations, so it appears to be, even more closely, associated with the same agents in the production of the restored re-crystallizations. Hence it would be equally correct, for our present purpose, to ascribe all the reconstructions of which we are speaking, to the three well known agents of metamorphism, viz., *heat*, *pressure* and *moisture*. When these combine in their action on any of the early sediments, such as may have been long subjected to levigation and hence may have been greatly changed from their parent condition by the ocean, the concentrated effect is to cause the greatest degree of re-crystallization, and restoration of primary characters.

These two opposing processes produce characteristic mineral species, and in their multiform physical reactions upon each other, under constantly varying physical relations, and varying chemical surroundings, they give rise to a large number of intermediate and unstable mineral species, which are characteristic of neither one nor the other. Such are the zeolites, the sulphides, some carbonates, etc. But the principal characteristic minerals which each process gives rise to, are too familiar to need enumeration here.*

Now, as both these processes result in a change of mineral condition in the rocks, the resultant rocks may be said to be metamorphosed. Indeed, the term "metamorphic" has been applied to each. Those who are predisposed to consider all rocks sedimentary until they can be proven to be of eruptive origin, have been prone to apply the term "metamorphic" to not only those banded schists (the mica schists) which preserve a plain sedimentary structure, but also to those greenstone schists which do not preserve evident sedimentary banding, but whose minerals are fragmentary and plainly in a state of transition from a once more perfectly crystalline condition to a state of greater disintegration.

*The chemical potentialities of silicon being called out mainly at high temperatures, and those of carbon at more moderate temperatures, they seem to stand, as it were, at the two opposite poles of matter, dividing the empire between them into what we commonly call the Organic and the Inorganic, but with very undefined boundaries along which dwell a series of restless and turbulent tribes, the individuals of which own no permanent allegiance to either, passing from the domain of each into the other in the most facile manner.

On the other hand, those who have been prone to claim every crystalline rock as eruptive until it can be proven to be of sedimentary origin, have been equally liable to ignore the necessary great divergence between these two operations, and to set down as eruptive not only those massive crystallines which are plainly eruptive, but also those imperfectly crystalline masses, whose grains are in a transitional state, like the schistose greenstones, attributing their semi-disintegration to a force or a process known as "dynamic metamorphism."

For the present purpose we shall apply the term *metamorphism* only to the reconstructed rocks whose minerals have been forced to take on a condition of more thorough crystallization by the application of the forces of heat and pressure in the presence of moisture. The micaceous and hornblendic schists, the Vermilion series, as above described, illustrate this metamorphism. The gneisses into which the Vermillion schists pass conformably, downward, also illustrate it perfectly. All other rocks whose minerals are changed by weathering, from the crystalline condition in which they were when the rocks were formed, may be styled *altered rocks*. Here, however, there is danger of assuming a condition to have prevailed in a large class of rocks that have been much studied, which the facts will not prove to have been their condition. I refer to the greenstones and the green schists, as a group, although there are plainly unimportant portions of these green rocks which should be excepted.

Again, there is a tendency among those who have been familiar with the structures of sedimentary rocks, on the one hand, to carry their ideas of sedimentary structure too far, and to make all the "parallel structures" which they see pervading the crystalline rocks, so many modified forms of sedimentary structure; and on the other hand a class of geologists who have become familiar specially with the structures that crystalline rocks may be made to assume under pressure and partial fracture causing the schistose arrangement of the entire mass, have been inclined to subordinate to mechanical causes acting subsequent to solidification, all those "parallel structures" which they may discover in a crystalline rock, however plainly they may have originated from sedimentation. To one class of observers, however many mistakes they may fall into in interpreting all these structures as due to sedimentation, the terms banding, lamination, schistose, gneissic, sedimentary structure, cleavage, &c., all mean fundamentally the same thing, and with great confidence sometimes they make out a "synclinal" structure for a great area, and have no more basis for it

than a superficial synclinal arrangement of the slaty cleavage. To the other class of observers, however great the apparent absurdities into which they may fall, these structures signify equally but one thing. They extend an observed result, viz., schistose or slaty cleavage, a product of pressure and shearing in a rock mass, not only so as to destroy its true, normal significance, but also so as to include structures that are known to be produced only by sedimentary forces—they attribute to pressure and dynamic metamorphism all the banding and stratification which some crystalline rocks so plainly manifest. These terms, therefore, about the significance and applicability of which so much has been written, have come to be the weapons which either party may use with perfect success, so long as they have no definite meaning. It is plain that, in order that either one or the other party shall finally prevail the distinctions which should mark these terms when correctly applied, must be ignored, and as far as possible broken down. The plutonist is inclined to ignore all the evidences of sedimentary structure in these questionable rocks, knowing that he has a firm starting point in his argument, and he ruthlessly drives the extreme of his argument into conflict with a set of important facts and structures coming from another direction. The neptunist, starting from an equally firm datum, with his eye only on one result, following his bent with equal rashness, finds himself soon beset with such problems and snares that he wantonly assails or denies evidence which is as valid as that which formed his point of departure. There must be certainly some middle ground. There must be some significance for these terms which, when carefully adhered to, will prevent one truth from apparently clashing against another. To adjust these differences by a consistent use of these terms, seems to be the most reasonable first step. It cannot be denied that there is such a thing as sedimentary bedding and banding, but this should be followed only so far as it can be distinguished as such, leaving all beyond to some other possible explanation. There is also with equal certainty, such a thing as a "diabasic structure," *i. e.* a structure resulting from crystallization from a molten magma, and so far as it can be followed, without essential modification, it ought to be allowed its full force. When its typical characters fade out, and the rock may possibly be ascribed to a different cause, it is unfair forcing of the evidence to insist that the "diabasic structure," feebly discernible, shall interpret the whole rock mass if the mass exhibits any other adverse structures.

In the field it is very easy to distinguish a true sedimentary banding(1)* from all those other structures into which it has been supposed to graduate, and with which it has been confounded. On the weathered surface it is indicated by varying shades in the color-bands that cross the surface, and on close examination it will be found to exhibit, in the different bands, or beds, which may be of any thickness from a sixteenth of an inch to several inches or several feet, not only a difference in the sizes of the constituent grains, but generally a difference in the relative abundance of the same. Usually free quartz grains will be found more common in some of the bands than in others, giving rise to lighter colored and harder layers. It so happens that very frequently the upheaving forces which have caused the strata to exhibit their truncated edges, have at the same time subjected them to such pressure, in a parallel direction, that the same rocks exhibit a finer slaty cleavage parallel with this sedimentary structure, and as the process of weathering brings out the slaty cleavage conspicuously, while the original bedding may become obscure, in case the cleavage direction gradually becomes discordant with the bedding the observer is liable to follow the cleavage in his measurements of dip and strike, under the impression that the two structures are essentially concordant. This structure which is due to sedimentation has another characteristic, viz: The coarseness observable in any chosen layer of the rockmass will be found to change gradually to one of considerable fineness, (and *vice versa*) in crossing the structure perpendicularly. There may be abrupt transitions from coarse to fine, or from light to dark, but these are not so sure evidences of sedimentary action as those gentler transitions which sedimentary materials take on under the gently changing force of currents. These color-bands will be found to maintain their courses independent of all other structures, and when they are not parallel with the schistose structure or with the slaty cleavage, the schistic structure and the cleavage will be seen to take on varying characters from layer to layer, as they cross the sedimentary beds. In general, the slaty cleavage (as well as the schistose structure) ceases, or becomes less and less evident, on entering the coarser beds. Indeed it appears to be a general principle that slaty cleavage only occurs in clastic beds of very fine grain. Clastic beds that have great uniformity, through grêat thicknesses, both in composition and in fineness of grain, when subjected to great pressure in two or more directions, and especially if a shearing movement be produced in the mass, take on a schistose struc-

*No. 1, of the figure on page 16.

ture (2). This consists in an initial production of slaty cleavage in two or more directions, cutting the rock into rhomboidal masses of greater or less fineness. These rhombs may then be more and more elongated in a uniform direction, all the constituent grains suffering a slight disturbance and sometimes fracturing *in situ*, some of the finer grains or fragments streaming out into tails in the lea of the coarser grains. When the stretching is extreme there is apparent a pseudo-streamed structure, and even a close pseudo-basaltic jointage, which gives the apparently once plastic mass a great resemblance to true irruptive (plutonic) rock. This dynamic action results at first, of course, only in a partial destruction of the integrity of the rock, and of its embraced mineral grains, and so far as it ceases before sufficient heat is produced or concentrated to reconstruct the minerals, it is entirely a degradational process, and fits the rocks so affected, better for the destructive action of the elements. A very great difference is observable in those cases in which the shearing movements were sufficiently intense to cause fusion, or to cause a reconstruction in part or in whole, of the minerals of the rock. (3) This, however, is a phase of the subject which will have to be considered separately. I desire here only to call attention to one important fact, which distinguishes the schistose structure, and slaty cleavage, wherever produced in massive rocks, from the sedimentary structure already described, viz: There is no transference of the constituent grains *across the structure*, and no selection of the coarser or of the more siliceous portions and the arrangement of them in separate and continuous bands or sheets that show any parallelism like that of sedimentation. Indeed when the two structures are seen to cross each other, they are always very different, and they are invariably contrasted in this particular. As these three structures—or more correctly these two, since schistosity is an extreme and confused development of cleavage—have so widely different origins, and can be distinguished by so obvious a character, no competent observer ought to confound them, and in the choice of terms he ought always to restrict each to its proper object.

These two structures are both found in nearly all the crystalline terranes, the only exceptions being those rocks which are plainly the result of cooling from fusion (4), which constitute only a subordinate part. The schistose structure, in some form, pervades all the Archean complex, including also the irruptive rocks, although it is plain that its origin in the irruptive rocks which have invaded the fragmental, is of later date and its development necessarily less perfect, than in the fragmentals themselves. It here takes on

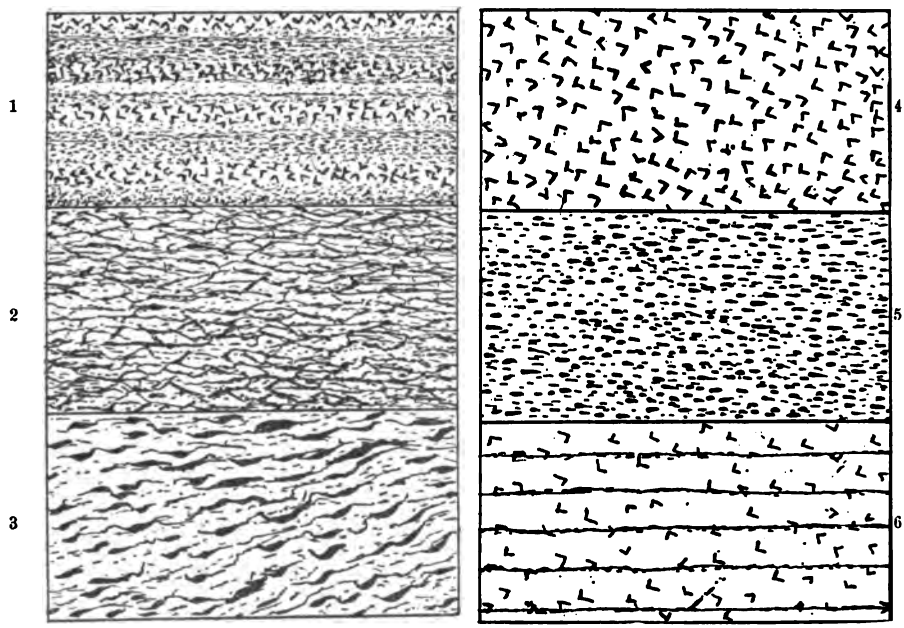
the form, sometimes, which is more frequently denominated gneissic, as it is found in some of the crystalline massives. Reference is not made here to a true intersheeted, sedimentary structure(1), such as characterizes the mica hornblendic schists and the gneisses into which they gradually pass—sedimentary rocks re-crystallized *in situ*—but to a homogeneous, or nearly homogeneous, acid rock, evidently the result of crystallization from a molten or plastic condition, classed as granite or syenite ordinarily, or as simply gneiss, in which there is a roughly parallel structure in the mass, caused by the elongation of the mineral crystals all in the same direction(5). This is a very feeble "schistose" structure, and ought to be separated from the term entirely, as it is due apparently to another cause, viz.: a slight fluxion in the mass while the crystals were forming. Again, the granites carry this "gneissic" structure to a still greater development, and it is apparently some form of the same which is seen in a kind of foliation (6) by which they are separable into irregular layers or sheets from an inch to three or four inches thick. This foliation differs from the gneissic structure already described, in having a bedded rifting, which becomes conspicuous on weathering and which embraces large areas in a common strike and dip—while at the same time the layering is not attributable to sedimentation, of which it does not show the characteristic color-bands, and the peculiar intergradations of coarseness and fineness. This higher development of the gneissic structure may be attributed at present to successive applications of heat at different temperatures or to fluidal flowage while the mass was molten or plastic, although it has been taken very largely to be the remains of an original sedimentary structure. Its cause is still problematic.

In respect to the diabasic or ophitic structure in basic eruptive rocks, when it is well exhibited there are perfectly formed, lath-shaped plagioclase crystals disseminated among the imperfectly formed other crystals of the ground mass. This structure rarely appears in the granitoid acid rocks. When it does, porphyritic crystals of orthoclase with idiomorphic outlines, are surrounded either by a micro-pegmatite of quartz and feldspar or by a finer crystallization of all the regular minerals that constitute the rock. In either class of rocks this structure is considered one of the surest evidences of the igneous origin of the rock. The amygdaloidal structure, which is produced by superficial cooling, is also one of the original characters of igneous rocks, although there is

produced in sedimentary strata* sometimes, when intensely affected by heat and pressure, but not reaching fusion, a spottedness, and even a partial vesicularization in which certain minerals are segregated, which strongly resembles the true amydaloidal structure of igneous rocks.

If the foregoing principles be applied to the various forms of structure, and the terms as defined above be employed to express them, there might be constructed a tabulated embodiment of this terminology which would take the form seen on p. 17. In this table the usual characters due to weathering and final disintegration, and to kaolinization, are not included. The table is designed only to express those structures, both original and secondary, which the Archean sedimentary and igneous rocks are found to assume in the field, and to ascribe to each structure its cause, and some of its relations to other structures.

FIG. 1. STRUCTURE OF CRYSTALLINES ROCKS.



*Parker Cleaveland stated in 1822 that the amygdaloidal structure is sometimes seen in bedded and clayey rocks, or "indurated ferruginous clay." "An elementary treatise on mineralogy and geology."—Vol. ii, p. 753.

2 s

TABLE OF ORIGINAL AND ACQUIRED ROCK STRUCTURES.

		CAUSES.	REMARKS.
SEDIMENTARY ROCKS. Original.	*Stratification.* (1) Color-banding and graduations in kind and size of grain across the bands.	Sedimentation.	When the grains are not of quartz they are blurred by decay. Crystal outlines not perfect.
Acquired.	(2) *Slaty-cleavage:* The grains flattened in the same direction.	Pressure in one direction.	This is usually simple compression.
	(3) *Schistosity.* The grains elongated in the same direction.	Pressure in two or more directions.	May be accompanied by shearing. No. 2, of fig. 1.
	(4) *Bedded Gneiss.* Reconstructed crystalization, *in situ.*	Deep-seated hydrothermal agents.	When fused this rock becomes igneous (acid) No. 1, of fig. 1.
	(5) *Fusion* and displacement; crystallization. *Augen-gneiss.*	Heat and shearing pressure.	This is strictly then an igneous rock. No. 3, of fig. 1.
IGNEOUS ROCKS. Original.	(6) *Granitic.* Homogeneously massive.	Normal and uniform cooling.	Applicable to both basic and acid rocks. No. 4, of fig. 1.
	(7) *Porphyritic.* (Acid and basic rocks)	Two consolidations.	Earlier crystals idiomorphic. In acid rocks, quartz and orthoclase.
	(8) *Ophitic.* (Basic rocks.)	Two consolidations.	Plagioclase crystals idiomorphic.
	(9) *Amygdaloidal.*	Rapid cooling; generally at the surface.	Later formation of zeolites, calcite, etc.
	(10) *Gneissic.* Uniform elongation of the mineral grains.	Fluxion at time of consolidation.	The rock remains massive—*i. e.* not foliated. Massive gneiss. No. 5, of fig. 1.
Acquired.	(11) *Schistosity.*	Shearing pressure.	Perhaps caused also by multiple cleavage. No. 2, of fig. 1.
	(12) *Foliation.* Regular parting-planes in massive rocks; slight formation of mica along the partings.	Cause uncertain.	Perhaps alterations of heat at different degrees. Foliated gneiss. Jointage is not here included. No. 6, of fig. 1.
	(13) *Foliation and Augen-gneiss.*	Shearing after consolidation.	Sedimentary "foliation" is not here included. Foliated gneiss. No. 3, of fig. 1.
METAMORPHIC ROCKS. Acquired Characters.	Reconstructed crystallization *in situ;* may show any of the acquired characters of sedimentary and some of those of igneous rocks.		

In what follows we shall employ these terms as here defined. We must insist on the actuality and the validity of both of these characteristic structures as they appear in their original rocks, *i. e.* on a sedimentary structure and on an igneous structure, because it is impossible to deny the existence of either, and wherever these contradictory structures appear to exist cotemporaneously in the same rock-mass, we shall try to find some means of reconciling the contradiction, or to show that the supposed existence of both is due to either an incorrect initial underlying philosophy, or to mistaken observation.

COMPARATIVE VALUE OF MICROSCOPIC AND FIELD EVIDENCE.

There is an essential difference between the evidence derivable from the microscope and that which comes from the study of the rocks in the field. At first glance it would seem that there could be no misunderstanding of the nature and relations of this different evidence, but here is where one of the fundamental errors has been committed. It is in the nature of the problem involved in the study of the complicated structures and relations of some of the Archean rocks, that the difference between the microscopic evidence and that derived from their macro-structure shall gradually fade out, and that one or the other shall usurp the whole field. This has already been alluded to. It is plain, therefore, that the two investigators, one following microscopic and the other field evidence, on a certain line of observation, would certainly reach a point, where, in respect to a certain structure, or a certain rock-mass, they would be at point-blank disagreement. That is, to the question: *Is this a sedimentary rock?* One would answer *yes*, and the other would answer *no*. It is in such a case as this that there is need of examining into the underlying principles through which these different results may have been reached.

It should be observed, at the outset, that the microscope takes cognizance of the intimate structure of the rock. Of itself it cannot observe the macro-structure, nor know anything about it. It cannot of itself take note of stratification nor of schistosity nor foliation. These are objects for the student of field relations, *i. e.*, as to their existence or non-existence. On the other hand, the field observer, of equal capacity and veracity, takes no notice of the intimate structure—or only so far as the unaided eye can detect it—and derives his conclusions from characters which are obvious. In each line of observation, the experienced observer, or the specialist in the microscopic phenomena studied, should be

allowed to have his own way. His determination of the questions arising within the normal sphere of his observation should be allowed to stand. It is only when one or the other transgresses the limits of his specialty that his conclusions may be questioned in case of conflict. If the field-observer extends his theories of sedimentary structures, either original or modified, beyond the limits of actual observation, in contravention of the conclusions of the microscopist, his theories must give way to those of the microscopist. If the microscopist extend his theories beyond the limits of his domain, and attempts to draw conclusions as to megascopic characters, or physical structure, in contravention of the determinations of the field-geologist, he is equally outside of his legitimate sphere, and his results cannot stand against those of the field-observer. This is not intended to shut out any individual geologist from exercising the right to employ any and all lines of research for the solution of all the problems that he has to solve. It is only intended to call attention to the different spheres and qualities of the different kinds of evidence, whether these kinds and spheres be in the hands of different geologists, or both in the hands of the same geologist. Indeed it is the individual geologist, generally, who handles both these sorts of evidence, who is driven to weigh them carefully and to separate between them when they collide. It is for the satisfaction of the individual geologist that this contradictory testimony must be examined into, and each given its legitimate weight.

Now the existence of a sedimentary structure in a rock is one of those outward, megascopic characters which the field-geologist only can be allowed to pronounce upon with authority. The structure itself in any normal case is so evident that none will doubt its existence—the doubt that arises in any special case is that of its genesis, and hence whether the case in hand be a true sedimentary structure. The field-geologist can perchance trace the structure back by degrees to rocks that show it in unquestionable perfection. He cannot deny the testimony of his senses. The microscopist, on the other hand, may have followed his minute characters with equal assurance till they have been traced into this banded rock and he now affirms that this is not a true sedimentary structure, but is one produced on originally irruptive rock by secondary causes, such as pressure, shearing or brecciation in parallel lines, followed by substitution of greater amounts of quartz along the planes of brecciation. That there are cases of such contrariety of opinion there is no question among the geologists who have worked among the crystalline rocks. We presume

here a case in which the observers are both competent and reliable, and whose veracity and judgment no one would willingly call in question. It is evident, however, that one or the other is wrong. It is the desideratum here to determine which is correct. It would seem to be a fair adjustment, other things being equal, to allow each observer in his own special field to have his own way. It is pertinent then to inquire whether the field-geologist or the microscopist is here trespassing beyond the limits of his legitimate field, and usurping functions that do not belong to him. The grand structures of a rock-mass are observable and comprehensible by all observers, and they cannot be misnamed, nor can their significance be reversed by anyone. They cover and precede all minuter inspection by the microscope. They cannot be denied by the microscope. If the microscopist by a laborious course of observation and speculation reaches a conclusion that contravenes the conclusions correctly based upon the grand rock structures, the microscopic conclusions must give way or must be amended so as to agree with the truth, which is evident to everyone or which is the result of study of patent facts correctly interpreted. In the same manner sometimes the paleontologist exalts his results above those of the student of physical structure and denies some of the most obvious truths of geological succession. He forgets that paleontology is nothing unless it be preceded by stratigraphy, and that unless there be a predetermined order of succession in rock masses, his paleontological results could not be arranged as historical data. In the same manner that stratigraphy involves and governs paleontological reasoning, so does the macro-physical structure of crystalline rocks govern and involve the study of their micro-structure.

Now let us take a concrete case. Unfortunately the differences which formerly separated the plutonist from the neptunist have not been reduced materially by concession and by demonstration of error, on one side or the other, to any limited group of rocks. Therefore we may take our concrete example from the so-called greenstones, which is a class which exists in nearly all parts of the world where the Archean rocks prevail. We will choose a rock which manifests one of the structures whose origin is in dispute between the microscopist and the physicist, viz:

1. ACCORDING TO THE MICROSCOPIST.

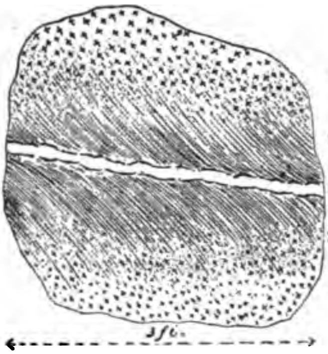
A rock alternately schistose and massive; the schistose sheets being much more broken and decayed, in their granular structure, than the massive sheets, and having a distinct parallelism in the

direction of the constituent grains, with the ophitic structure completely lost; the massive sheets being of more perfect and evident crystalline integrity, and having the schistose arrangement seen in the granular condition of the schistose sheets only faintly observable, while there is preserved, with more or less distinctness, an occasional trace of the ophitic structure. These features, as they alternate, produce on the surface of the rock a parallel banding resembling stratification bands.

2. ACCORDING TO THE FIELD-OBSERVER.

A stratified greenstone, alternately striped by bands of lighter and darker green. The schistose character, which sometimes is rather a slaty cleavage, is more evident in the finer beds than in the coarser ones, or wholly disappears in the latter. It does not agree in direction with the course of the stratification bands, but crosses them at an acute angle which angle vanishes as the finer beds grade into the coarser, also changing a little in direction so

as to approach nearer perpendicularity to the grand bedding—showing apparently a shearing pressure to have been its cause.



The structures here referred to are illustrated by the above figures, which are taken from bulletin No. 62, of the U. S. Geol. survey (Williams), where they are referred to dynamic metamorphism and are said to be in no way dependent on sedimentation. These figures could be repeated many times in the course of a brief examination in the field. These cases present the issues fairly. It remains to be decided whether the testimony of the student who relies on his microscope, and starts out with the idea of subordinating his facts to the answers it may give, or that of the field-observer, who only studies the grander structures and has a predisposition to explain such as the foregoing by referring them to sedimentation, shall here be received with the greater credence.

THE PHILOSOPHY OF DYNAMIC METAMORPHISM.

It has been stated already that the term metamorphism is applicable to these rocks whose constituent grains have been reconstructed by a second crystallization by the action of heat, pressure and moisture, a process the reverse of weathering, by which mineral grains undergo a degradational change. But the term "dynamic metamorphism" has been applied extensively to a set of changes that do not fall within the meaning of metamorphism as thus defined. It has been employed to explain the structures seen in the greenstones, such as schistosity, color-banding, foliation, and also all those minute imperfections in form, and the chemical transitions that the minerals of the greenstones exhibit. Hornblende wholly or partly converted to chlorite, is a degradational change. Saussuritization, a decay in a plagioclose feldspar, is a

degradational change. Augite converted to hornblende is a step toward ultimate disintegration and decay; ilmenite changed to leucoxene, or to sphene, is on the road to decomposition and loss. Orthoclose kaolinized is ready to disappear on the approach of the feeblest physical disturbance. These alterations, all of which in other rock-masses are attributable without question by any one to weathering and destructive agents, are assigned, as stated by some microscopists, to "dynamic metamorphism," which therefore would be a metamorphism in the opposite direction from that which is usually understood by the term. There is no inherent valid objection to the use of the term in this sense, so long as it is clearly understood what kind of a change is meant by it. The most important point to be considered in the application of the term, is whether the assumed cause, if it should be found to have operated, could produce the effects which are seen, and whether it is the only cause which could produce those effects. The forces of dynamic metamorphism as defined and applied are wholly mechanical and then chemical. Heat and moisture are not included. Shearing pressure, direct pressure, stretching and fracture are all appealed to.

There seems, however, to be an *a priori* inconsistency in supposing that mechanical force can be applied in sufficient intensity to crush or partly crush a rock-mass and yet not to produce a perceptible degree of heat. And there is much room to doubt the possibility of such crushing in any natural rock-mass within the super crust, without the presence of moisture. While it is apparent on every hand that great deformations have taken place under the action of mechanical forces, producing upheaval, stretching, faulting, brecciation, cleavage and schistosity, it is equally apparent that where these changes have taken place in their greatest intensity the rocks have been fused and recrystallized; many examples could be given. Hence it is evident that where these forces have acted to produce less mechanical deformation, there was a smaller amount of developed heat, but not an absence of it. If mechanical force be applied therefore to a rock-mass, with shearing friction so as to disturb the grains in respect to each other or to crush some of them, the inevitable effect of the heat which is generated thereby is not a degradational one, but a reconstructive one, and, aside from the more easy weathering that might be a consequence when such rocks were exposed locally to the action of the elements, the crystal grains would be strengthened in their chemical bonds, and perhaps built out afresh in their natural contours. If a degradational change be generally observed throughout the

interior of such rocks, it is unreasonable to attribute it to mechanical force *per se* operating to break the grains. It must be explained by appealing to some other cause.

Again, the philosophy of dynamic metamorphism, if not at fault fundamentally, must explain a singular anomaly. The greenstones as a body everywhere are younger than the crystalline schists as a body, but they grade into each other imperceptibly, passing through the intermediate stages of sericitic schists and graywackes. The greenstones and their appendages, the chloritic schists, must have shared in no mechanical transformations to which the underlying crystalline schists were a stranger. It would be a physical impossibility to subject the overlying schists as a body to dynamic metamorphism, (pressure, shearing and crushing) without including the lower schists, and if the forces of dynamic metamorphism be accountable for the semi-decayed condition of the "greenstones," why was not that change wrought also in the crystalline schists? On the contrary the crystalline schists, normally, are fully and perfectly crystalline still—as perfectly crystalline as any granite or gneiss, only differing from the great mass of the Archean gneiss in physical structure, or in the relative amounts of the contained minerals.

THE ANOMALOUS CHARACTERS OF THE GREENSTONES AND THE GREEN SCHISTS.

No thoughtful student of the crystalline rocks can fail to note, as long since claimed by T. Sterry Hunt, an order of succession in the relative abundance of certain minerals that constitute the Archean rock-masses. He hence also notes an order of succession of kinds of rocks. In Minnesota this order has been found to be the same as that worked out in Saxony, Italy, western France, Scandinavia and Great Britain. The same succession has been published by Lawson for the crystalline rocks of Manitoba. In each case there is a body of greenstones, associated with chloritic and sericitic schists, which forms the summit of the Archean terrances. In other words, it has been found that there is, first, a great series of acidic crystalline granites and gneisses at the bottom, these sometimes exhibiting unmistakable evidence of fusion and displacement among later bedded schists, and hence locally overlying the schists. These thoroughly crystalline rocks are followed by a series of equally crystalline schists which contain much mica and hornblende, and vary from acidic to basic. In the upper portions of these, which are here distinctively called "crystalline schists," there is an increasing amount of non-crystal-

line, or semi-crystalline, matters, and here the detritus has been found to consist very largely of unmistakable volcanic tuffs, intermingled minutely with chemically precipitated silica. Somewhat higher, but connected by a series of conformable gradations, both stratigraphic and petrographic, are the greenstones and chloritic schists. So far as known these constitute the highest portion of the pre-Taconic complex. As a grand division of the Archean they approach nearest of all the Archean rocks in their mineralogic characters, as well as in their physical structures, to the well-known characters of basic eruptives. It is a remarkable fact that the first detrital depositions of the Taconic sea, which lie unconformable above these greenstones and chloritic schists, and which extend further back and also overlap in the same manner the crystalline schists and the older gneisses, are highly acidic normally, although affected locally by debris referable directly to the rock underlying or to volcanic tuffs. It appears, therefore, that the greenstones are interposed with their anomalous mineral characters, chronologically between two epochs whose rock-formations were dominated by more acidic characters. It appears also that on the lower side there is a gradual transition from the oldest acidic into this highly basic, but that on the upper side the transition is abrupt from the highly basic to the highly acidic accompanied by a widespread, pronounced unconformity of stratigraphy. It is this general semblance of the greenstones, as a body, and the identity of some portions of them actually, with well-known characters of eruptive diabases, which furnishes the most evident and powerful argument for their derivation from true irruptives through a series of long-continued so-called "dynamic" changes, and which is the chief obstacle to the neptunist in his attempt to assign them to an aqueous origin.

There is a great significance in this anomalous mineralogical character of the Kawishiwin phase of the Keewatin, and in the nature of the transitions to it from above and below. In general it points to a gradually increasing force in that agent, whatever it was, which gave origin to the "greenstone" element of the Keewatin, and to a rather sudden culmination and cessation. It further points to such a shrinkage of the bulk of the earth's land surface, compared with that of the water area, that the ocean's waters prevailed over large areas which had before been dry.

THE NATURE OF THE CAUSES WHICH GAVE ORIGIN TO THE CRYSTALLINE ROCKS.

It has been customary to speak of the crystalline rocks as a unit, and to refer their existence to the operation of a single force. In

a broad sense it may be legitimate to refer them to one cause—the refrigeration of the earth—or to the action of gravitation in its specializations—but as geologists we are bound to inquire more closely. So long as we knew of no widespread, or even local, serial succession in these rocks we could but speculate on them as a whole. But since now they may be differentiated into groups having marked distinguishing characteristics, it is incumbent on us to find a cause for each group. In has been one of the striking facts in the history of geology that geologists have specialized more and more, in their observations, and have been compelled to separate their generalizations into several parts, applying only a part of their former ideas to some special phenomena, and being compelled to recognize new principles in order to explain the rest. There is, however, one great feature which binds the Archean rocks into one great group, and which indicates that they have shared in one sense in a common history. They have been upheaved and pressed together in sharp folds so that now they present everywhere in Minnesota (and the same is true of the whole Northwest and for Canada) their truncated edges vertically, or nearly vertically, to the observer. After this upheaval and truncation they were submerged beneath the Taconic ocean—at least the Taconic strata now lie, in attitude sometimes horizontal, unconformable upon them, presenting one of the most notable and widespread instances of unconformity of stratigraphy, and one of the most remarkable changes in lithological characters. In the sense then of constituting a "floor" on which the admittedly clastic strata repose, those rocks may be classed as a unit, and may be said to occupy a single period in the earth's geognosy entirely unique and separate from all the other periods. Yet when we look at the series by itself we soon see that there is no other equal amount of rock-material in the purview of the science of geology which presents so numerous and so great contrasts of composition, and yet which presents a greater persistence in the orderly succession of its main parts. We are forced therefore to note, as the *first* element in the nature of the forces that evolved the crystalline rocks, that they were not local in their extent, but were apparently world-wide, and as such succeeded each other in their operation.

Secondly. Although there is a profound stratigraphic break between the Taconic and the uppermost member of the "Archean floor," yet it is plain, by the existence within the Taconic of rocks of the same nature as those of the "greenstone" stage of the Keewatin, that the close of the Archean did not witness the suppression of the characteristic forces of the Keewatin. Those forces (plainly

those which gave origin to basic eruptive materials) simply waned after the Taconic began, and finally ceased to have any marked effect on the clastic sediments.

Thirdly. As the banding and schistosity, and the elevatory movements which gave the Archean rocks their present position and trend, forming certain geographic areas, all of which took place in Archean time, have a general parallelism with the strike and the areal increments of the Taconic rocks in their present distribution at the surface, there was a continuation of the Archean genetic forces into the Taconic—*i. e.*, those forces which give rocks their elevation and strike, and a persistent order of growth to continents.

Fourth. The order of succession already mentioned from the volcanic Keewatin, giving birth to its basic debris, downward with a gradual, and not a sudden transition, to the acidic gneisses, shows a very gradual waning of the eruptive forces in descending order, and points to some other force than eruption for the origination of the basal Laurentian gneisses.

As the primarily eruptive basic tuffs of the Keewatin, distributed like sediments in the Keewatin sea, assume some characteristic new mineralogic features on passing conformably into the "crystalline schists" below, there is proof (*fifth*) that the deeper-seated portions of these schists have undergone some later transformation which the upper portions did not experience, and that, therefore they have been acted upon by some reconstructing agents whose seat and source are from below. As this force had a similar effect on the acidic portions of the Keewatin, when associated with the basic, and as these acidic elements gradually become *per decensum* the acidic elements of the mica-hornblendic schists, and finally, increasing over the basic, become the characteristic element of the gneisses, we can trace the continuation of a force or forces from the Keewatin back into the Laurentian, such not only that they could give origin to the common acidic element, but could later transform it into the acidic crystalline gneisses.

It is necessary, therefore, to recognize various forces concerned in the production of the elements and the crystalline structures of the basal rocks, and it is necessary further to allow them to act in a sort of succession. As to the nature of the materials, however, they are primarily reducible to two kinds—very acidic and very basic, standing at the extremes of the stratigraphic order. Everything between consists of gradations, stratigraphically conformable, between these two. The eruptive force which was most powerful in the production of these basic rocks at the close of the Archean

scarcely acted at all at the beginning, or at least it left no records, and that force which transformed the lower materials into crystalline forms was different from and acted later than those which gave them origin. It is necessary also to account for a sudden cessation, or at least a remarkable reduction in the activity of volcanic forces just before the opening of the Taconic, and for that universal crumpling and almost vertical attitude which the Archean strata exhibit.

II.

FIELD NOTES OF N. H. WINCHELL,

IN 1890.

Northern Pacific Junction. Slate quarries of Dietz and Dugan; about three miles north of N. P. Junction, Oct. 16. Calcareous but soft, rusty lumps appear here in the same manner as at N. P. Junction, and at the falls of the Vermilion, northwest from Sudbury in Ontario, furnishing a strong lithological bond of idenity of age. These lumps were first noticed here by Dr. T. Sterry Hunt, on occasion of an excursion of the American Association for the Advancement of Science, from Minneapolis, in 1883. These calcareous lumps are of dark gray color within, approximating the color of the slates, but they are granular and crystalline. They decay superficially and become spongy, acquiring a darker shade. (Compare rock samples 1591, 1607 and 1616.)

The slate extends at least to Cloquet, and is all of the same formation, at least from the quarry of Dietz and Dugan. It dips in opposite directions, showing several great anticlinals, the inclination being frequently 75°-90°, and rarely less than 50°. This refers not to the cleavage, which traverses the sedimentation, but to the sedimentary bedding. The general color, when fresh, is purplish-black, but on weathering this varies from gray to greenish-gray, with fleckings of lighter, this lighter flecking appearing where the rock is of coarser grain. The calcareous lumps extend all the way to Cloquet.

N. P. Jnnction, Oct. 17. I have looked over this formation with a view of learning certainly whether it be of the Taconic or the Keewatin. I had rather expected to see some resemblance to the Keewatin, on looking it all over, but so far as the west side of the river is concerned, I do not think I can say I have seen any Keewatin. There are some portions of the Keewatin that resemble this rock, but so far as I have ever observed they are a very small and unimportant part, and are associated with lithological features on which they depend, which are wanting here. This is nearly all a true slate, with a cleavage oblique to the bedding, though in two instances I saw them coincident. The slate is not all suitable for

economic purposes as roofing slate, but much of it is—i. e. so far as the quality and the grain of the rock is concerned. It is much jointed, and that fact may interfere with the practical development of slate in a profitable industry. This rock in general possesses a sameness of lithological character over large areas, and in this respect contrasts with the Keewatin which usually is much more changeable. It also possesses everywhere a distinct fresh sedimentary structure with ripple and other water marks. Another feature that allies it with the Taconic is the prevalence of those dark calcareous lumps or secretions. These are the same that Drs. Hunt and Dawson supposed to contain traces of a keratose sponge, and which Dr. Selwyn pointed out as "snow-shoe tracks" —so-called by the Indians—where their weathered contour-forms appear on the slates at the Vermilion river in the region northwest from Sudbury, Ontario. On the exposed surfaces these masses are dark brown and soft, from decay, and often present, when not subjected to friction at the same time, a suggestive resemblance to a semi-vesicular structure, the preserved mesh or net work that stands out beyond the softer parts being due to some trace of a more siliceous matrix. When these lumps are fresh they are gray, crystalline, apparently consisting essentially of lime, in which, in some parts, the small crystals of calcite are visible in compacted marmorized structure. But there is also a layered, concentric, rather coarse structure reminding one of Cryptozoon, across which perpendicularly there is a transverse jointage, or very fine "basaltic" disintegration. This perpendicular transverse disintegration is best characterized, as far as observed, in a layer that is nearest the outside, involving a thickness of about one inch. These limestone masses are in the midst of the finest-grained slate, and extend, with more or less frequency, from the N. P. Junction, where they were first seen in 1883, to Knife Falls (Cloquet), indicating that this is all of one formation, and allying it with the slate seen on the Vermilion river in Canada. They also seem to answer to some of the limestone "lentilles" which have been described by Mr. Marcou in the Taconic slates in Vermont. After considerable search, however, it has not yet been possible to say these masses are fossiliferous at this place. These limestone masses, broken and erratic as they appear, may be the remaining trace of the gray limestones of the Animikie at Thunder bay and at Gunflint lake. It may be that under other circumstances, and in other places, they would be found to increase, so as to become more continuous, and constitute limestone beds like those seen on the north side of

Gunflint lake. In every respect, so far as color, structure, composition and tendency to decomposition, as well as associated rock-strata can indicate it, these are the same as those.

As between this slate and that seen at the crossing of the Vermilion river, northwest from Sudbury, there is a perfect correspondence, and there can be no question of idenity of stratigraphy. Here the tracing to the Taconic, through the parallelization by Irving and others, of the original Huronian with the Animikie is more unbroken, though more circuitous. The above notes pertain to the rocks seen on the west side of the river at N. P. Junction.

Northern Pacific Junction, Oct. 17, 1890. After writing the foregoing a re-examination was made of the prominent ridges of slate immediately at and east of the depot, but still west of the river, north of the railroad track. Here the first thing noticed was the manner of distribution of these limestone masses. There is a plain confirmation of the idea that they are the analogue of the limestone layers of the Gunflint region. Not only are they numerous, varying in size from a peck measure to a walnut, but they run in belts coincident with the sedimentary structure, and in one instance they make a continuous layer, somewhat nodular, that extends for 33 feet at least, and maintains a thickness of about two inches, but vanishes toward the east. The layer is marked by a rusty surface coating which is nothing but the rusty oxidation seen on such rock at Gunflint lake. As limestone it is not pure, but very firm, gray and slate-colored. Except for its weathering out rapidly it could hardly be distinguished on the rock surface. It makes numerous elongated, lenticular holes over the surface, the origin and significance of which were not noted in any previous visit to this locality.

Besides the old Thompson test of the slates, the test of the St. Paul and Duluth R. R., about two miles south of Cloquet, and the recent one of Dietz and Dugan, there is now being made what will be a most thorough test by the C. E. Nelson Lumber Company, of Cloquet, at about a mile and a half south of Knife Falls. It is near the railroad, where an east and west ravine crosses it. The plan is to make at first a shaft about 75 or 100 feet in depth for the purpose of proving the character of the rock at that depth below the surface.

On the east side of the river the graphite locality, mentioned by Schoolcraft, is on n e ¼, n e ¼, sec 31, lot 1, about 4 miles north of Thomson, near the river, and near a creek, which enters the river. It is now owned by H. H. Hawkins, C. d'Autremont Jr. and D. V. Scott. The vein in which graphite is found is about 12 inches

wide. It amounts to but little. Some work has been done recently on the vein, the resulting excavation being about 20 feet deep. The vein itself is one of quartz, cutting the slates, and has much associated plumbaginous matter. Recent work was of no avail to show its importance. The formation here looks like the rock westward from Pigeon point on the international boundary.

A little below (but nearly opposite) the foot of the large island which is opposite the graphite locality, is a basic dyke about 25 feet wide, coming in diagonally across the river bank. It runs north 10° east, and is coarse-grained in general, but fine-grained at the side, having basaltified and hardened the slates. This may be in extension of a great dyke noted on the west side of the river some years ago not far from the slaty Fortress island.

The river roars with rapids much of the way, and at $\frac{1}{4}$ of a mile further south there is a fall of about six feet. At about two miles north from Thomson is a massive, light-weathering but gritty, rather coarse-grained stratum in this formation; and this also contains the rusty calcareous masses noticed in the fine-grained slates. This calcareous mass could hardly be distinguished from the rock in which it is embraced except for the rusty spot which it causes on the weathered surface (1616).

Apparently the old portage trail runs along near here, near the river, from Fond du Lac to Knife Falls. I imagined I put my foot in the same niches over the rock ridges that Schoolcraft, Houghton and Boutwell stepped on, and where thousands of furriers and Indians have stepped for more than 200 years on their trips from Winnipeg to Montreal.

The first rock-cut in gabbro, east of Thomson, is a short $\frac{1}{4}$ mile east of Short Line Park station, where the "Duluth deep well" was drilled about 1700 feet in search for gas. (See Bulletin No. 5). This is the station for old Fond du Lac, and a number of Indians here leave the train, with some half breeds, for that old town. They asserted that the old trail from Fond du Lac runs about four miles further east than where the graphite locality is known near the river, crossing the railroad (short line) at about one mile west of the Short Line Park station. This gabbro is like that at Rice's point, and the spur runs southwest from the main belt. There are also several other spurs further east. From this cut rises toward the east and northeast a marked precipitous range of gabbro. The track hugs the foot of this range with occasional cuts, until it has passed the head of a deep ravine, and then swings south to pass another spur, with several gabbro cuts further east as it descends to the terrace flats of the St. Louis river.

At the station called Sargent, a short distance east of Duluth, the usual "trap" of the region underlies the surface at the depth of a few feet. The excavations for water works are principally in red clay, but frequently encounter this rock, which is there well exposed by the blasting and cutting. It is reddish-brown, and in some places amygdaloidal with calcite, and at the same time has disseminated fine red crystals of some feldspar. On some favorable fractures this feldspar has the form of twinned tablets of some plagioclase, but generally it is not evidently twinned, but so crowded and compressed that no cleavage can be characterized, though evidently a cleavable mineral. It apparently also is disseminated in finer forms throughout the mass of the trap. The rock therefore is sparingly porphyritic, and conspicuously and coarsely amygdaloidal with calcite. 1615 is the above rock.

[NOTE. Most of the field notes of 1890 were incorporated in the report on the "Iron Ores of Minnesota," Bulletin VI, 1891. See also the accompanying list of rock samples].

ADDITIONAL ROCK SAMPLES NUMBERED.

[TO ILLUSTRATE NOTES OF N. H. WINCHELL],

IN 1890.

1607. Calcareous, soft, rusty lumps. Dietz and Dugan's slate quarries, about three miles above N. P. Junction. (See also 1616.)

1608. From near the old saw mill, a short distance north of the the last. A square slate piece showing lime seams on each side—joints that cross the slates in too great frequency for the good of the economic outlook.

1609. A fragment from an almost unweathered lump of the calcareous concretions abounding in these slates, broken from the hard fresh slates at the old trial quarry of the St. Paul and Duluth R. R., about 1½ miles south of Cloquet.

1610. Sliver from the slate showing fine ripple marks. Coarser ripple marks and other water-marks are common.

1611. Chipping from one of the calcareous nodules from the slates at N. P. Junction east of the village, north of the east and west railroad. This came from about the same place as that from which Dr. Hunt obtained the specimens in which were thought to be remains of a keratose sponge.

1612. Chipping from one of the lighter-colored siliceous, thicker beds in the ridges, six inches thick, north and east from the R. R. junction.

1613. Same as 1612, from a layer 20 feet thick. When fresh this is dense.

1614. Graphite and quartzose slaty rock, from the "graphite vein," N. E. ¼, N. E. ¼, sec 31, lot 1, T 49-16.

1615. Slightly porphyritic, and amygdaloidal trap, from Sargent, east of Duluth, from the trenches dug for water-works.

1617. Samples of iron, from Camp's land, S. W. ¼, sec. 33, a mile southwest of Ely.

1618. Ore from the narrow magnetic belt on Camp's land, S. W. ¼, sec. 33, about a mile southwest of Ely. (Iron ores of Minnesota, page 202.)

1619. Loadstone ore said to have come from the same place as 1618. (Iron ores of Minnesota, page 202.)

1620. A "quicksand" which is encountered at the bottom of the pits in the Anderson location, near Ely. It is very fine-grained and clay like. Are the grains angular, and referable to disintegrated jaspilyte?

1621. In the greenstone of one of the ridges on the S. W. ¼, sec. 33, about a mile southwest from Ely, is the indefinite rock which has been described in this region—neither greenstone nor graywacke. In the midst of it is a harder and more siliceous area, which seems to be only a phase of it, represented by 1621.

1622. A boulder was taken out from one of the pits by Mr. Camp, which represents another phase of the greenstone, but this is not seen in place anywhere about here. It may have come from north of Long lake. It is one of those coarsely crystalline (fragmental) greenstones, with free quartz grains and pyrite, and seems to consist largely of plagioclase and hornblende.

1623. Globular and nodular mixture of the white kaolinic and red hematitic soft rock, the two not mingling so as to stain each other though in immediate contact. From the dump of the Chandler mine. This kaolin seems to be one of the very early constituents of the rocks of the region, and not the result of recent change.

1624. Fragment of the amygdaloidal scale that surrounds the volcanic bombs seen in the rock-cut at Ely, and some of the matrix.

1625. Some of the dark-green schistose rock that fills the interspaces between the bombs.

1626. A piece of the bomb from toward the centre, away from the amygdaloidal crust. (American Geologist, Vol. ix, p. 359.)

III.

FIELD OBSERVATIONS ON

CERTAIN GRANITIC AREAS

In Northeastern Minnesota.

BY ULYSSES SHERMAN GRANT.

CONTENTS.

ILLUSTRATIONS.

INTRODUCTION.

In the summer of 1891 the writer, accompanied by Mr. Herbert R. Wood and one Indian canoeman, spent the greater part of the months of August and September in examining certain granitic areas in Lake and Cook counties, Minnesota. The areas visited are four in number, and may be distinguished as the following: (1) the Kawishiwi river area, which extends from the division of the Kawishiwi river in T. 63–10 west and southwest for a considerable distance;. (2) the Snowbank lake area, which is mostly confined to the islands and shores of Snowbank lake; (3) the Kekequabic lake area, in the immediate vicinity of the lake of this name; (4) the Saganaga lake area, in which the larger part of Saganaga lake lies. The object of the examination was more to study the age and origin of these granite masses and to ascertain their relation to the surrounding rocks than to make any minute study of the structures and variations of the granites themselves.

The present paper is simply an account of the phenomena as seen in the field, supplemented by but a small amount of laboratory study. A number of the rocks, especially the normal facies of the different types, have been examined in thin section, and considerable progress has been made towards a systematic study of one of these areas—that of Kekequabic lake. The writer hopes in the near future to be able to give a more complete account of the different rocks of this interesting area, both stratagraphically and petrographically.

On account of the incomplete character of the work and the lack of sufficient time in the preparation of this report it is thought best not to give a detailed description of each area nor to make any generalizations concerning the region studied. However, it will not be amiss to say a few words as to the results reached thus far. In the parts of the four areas studied there has been seen no evidence of a transition from the semi-crystalline and crystalline schists to granite. On the other hand there is abundant evidence to prove the true irruptive nature of these granitic rocks into the

surrounding sediments, notwithstanding the fact that these granites have been described as granitoid gneisses formed from the metamorphism of certain clastics and now seen to pass imperceptively into these same clastics.* The gneissic and so-called "bedded" structure in these rocks is not nearly as common as has been supposed, in fact the usual structure is truly granitic. The Kawishiwi river "granite," where studied, is a hornblende syenite, as is also that around Snowbank lake. The Saganaga granite is a very coarse hornblende granite. The granite around Kekequabic lake is a pyroxene granite, and associated with it is a peculiar pyroxene granite porphyry.

PART I. RECORD OF FIELD OBSERVATIONS.

In giving the township and range in the following notes the township is always north, and the range is always west of the fourth principal meridian, Minnesota, unless stated otherwise. The bearings given refer to magnetic north, no correction having been made either for general or local variation. When giving the strike and dip of slates reference is always had to the lamination, unless otherwise stated. As a rule the edges of the different granite areas have been studied, as here only could the relations to the surrounding rocks be seen.

KAWISHIWI RIVER AREA.

The examination of this area was confined entirely to its eastern end, and most of the notes were taken in the southern half of T. 63–10.

Pickerel lake.

Pickerel lake† is a small body of water cut by the line between secs. 24 and 25, T. 63–11, and secs. 19 and 30, T. 63-10. The shore where visited was found to be made of a more or less massive rock, which in all the reports on this region has been called greenstone or greenstone-schist. From the little bay of the Kawishiwi river in the N. E. ¼ of S. W. ¼ sec. 25, T. 63–11, a portage leads to the southwest corner of this lake. The southern half of the portage shows angular blocks of mica-schist, probably not far removed from their original position, and the northern one-third of the

*15th (1886) Annual Report, pp. 199-204.
†The Chippewa name for this lake is Gi-nó-ses, which is the word for pickerel.

portage is over a ridge of rather massive greenstone represented by Nos. 302, 303 and 304, the latter from the lake shore. No. 303 is, however, more like an altered graywacke and is quite schistose. The greenstone extends all along the south shore of the lake. It is shown by No. 305, which is very dark-green and schistose, and occurs just east of the portage, No. 306, more compact and silicious, and No. 307, which was taken from the outlet of the lake in the N. E. ¼ of N. W. ¼ sec 30, T. 63–10. At the east end of the lake just south of the section line the rock is green, very tough and massive; it presents the appearance of a consolidated volcanic ash (No. 308). Only one spot (S. W. ¼ of S. W. ¼ sec. 19, T. 63–10) on the north shore of the lake was examined; here the rock is a fine grained massive greenstone (No. 309).

A section was made from this lake south along a trail, which is almost on the range line, to the Kawishiwi river. Several low ridges were crossed, the general trend of the ridges being east and west. Just south of the lake there are no outcrops seen, but a low ridge of fine grained compact greenstone (No. 299) is soon reached. This rock is cut in every direction by minute, branching, yellow and pink veins; it shows no structural lines, but appears perfectly massive. On going farther south the rock becomes schistose, this structure being vertical and running east and west. It is cut by a small dyke, four or five feet wide, of a quartzless porphyry (No. 300). This rock held a small piece of the greenstone, which is very schistose at the dyke walls, otherwise not being different from that farther away. The dyke runs almost east and west and was traced rather disconnectedly for fifty feet. No. 301 shows the contact of the two rocks. Farther south occur several outcrops of a finely laminated schistose rock (No. 310) which approaches a mica-schist. The lamniæ have been twisted considerably in places, but the general strike is east and west and the dip is vertical. This rock continues nearly to the quarter post, but just before reaching this a rather course grained red syenite is seen (No. 311). The hornblende is roughly arranged in elongated spots, thus giving to the rock a decidedly gneissic structure, which runs east and west and stands nearly vertical. Associated with this syenite are small areas of a fine grained granitic rock (No. 312). This gneissic syenite continues about half the distance from the quarter post to the Kawishiwi river and then assumes a darker, finer grained aspect (No. 313) with the hornblende much more abundant than in No. 311. It now contains fragments from one inch to several feet in length of a dark mica-schist (No. 314); these fragments are mostly lens-shaped and their outlines are distinct. The

syenite also holds many veins, up to ten inches across, of a rather fine grained biotite granite (No. 315). At this place the gneissic structure in the syenite, the long axes of the mica-schist fragments and the general direction of the granitic veins are northwest and southeast. Mica-schist now extends to the river and also occurs on the little point in the S. W. ¼ of S. W. ¼ sec. 30, T. 63–10; here a little back from the shore is a low ridge of the schist (No. 316) which strikes 80° W. of N. and dips N. 65°. In it is an irregular vein of very fine granitic rock (No. 317).

Clearwater lake.

Clearwater* lake lies almost entirely in sec. 32, T. 63–10, with a small bay projecting into the E. ½ of N. E. ¼ sec. 31. Excepting a small area at the northwest corner of the lake near the portage north to the Kawishiwi river, the shores are composed of reddish syenite which is quite constant in character. In the S. W. ¼ of N. W. ¼ sec. 32, the syenite shows an irregular flow structure, which is more evident here than elsewhere on the lake, although seen in several other places. It twists considerably, but stands about vertical and its general trend is east and west. No. 337 shows this structure very well, although the lines are not usually as near together and as distinct as on this specimen. The syenite of this lake is well represented by Nos. 338 and 339, the former coming from the same locality as No. 337, and the latter from the extreme northern end of the little bay that extends into the S, W. ¼ of S. E. ¼ sec. 29. The rock is microscopically a rather coarse grained aggregate of hornblende and reddish feldspar in about equal amounts.

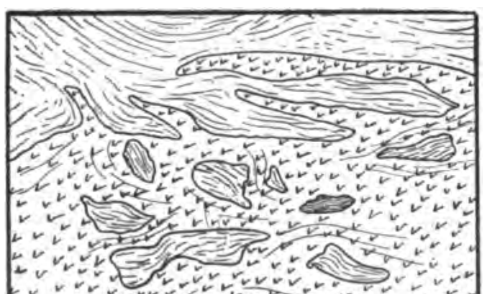


Fig. 1. Contact of syenite and mica-schist; N. E. ¼ N. E. ¼ sec. 31, T. 63-10. north shore of Clearwater lake.

Where the line between secs. 32 and 31 cuts the north shore of the lake the syenite is seen mixed in with mica-schist. See Fig. 1. The schist is much twisted and the syenite exhibits the flowage structure as shown by No. 337. Most of the syenite here is of the usual character, but

*The Chippewa name is Gawaukamik.

in some areas it is of a finer grain (No. 340). Just west of this place the syenite and mica-schist are seen in contact. The schist is much disturbed and twisted and the dip and strike could not be accurately determined, but the general trend is a little south of east with a very high northerly dip. The contact is irregular, but sharp, and is shown in the specimens numbered 341. No. 342 is the syenite within a foot of the contact.

At one place on the portage, running northwest from the lake, and in several places on the shore in the E. ½ of N. E. ¼ sec. 32, there is a dark green rock (No. 343) which is a coarse grained aggregate of hornblende with a small variable quantity of feldspar. It presents a very rough, jagged, weathered surface. It is cut by vein-like stringers of reddish syenite (No. 344) similar to the ordinary syenite of the region, by a gray variety (No. 345) of the same and by a small trap dyke (No. 346). The last is but four inches wide and was traced for fifteen feet; it is probably a very fine grained diabase. A section of No. 344, at the contact with the hornblende rock, shows the former to be composed of a granular aggregate of (1) an almost opaque feldspar, which, notwithstanding its alteration, shows some traces of polysynthetic twinning, (2) a fresh feldspar with abundant twinning lamellæ and (3) a few pieces of green hornblende; the two feldspars are in about equal amounts. The small part of the hornblende rock in the section is seen to be made up almost entirely of green, highly pleochroic hornblende; a small amount of the altered feldspar is also present. The two rocks are seen to be separated quite sharply even in thin section.

Mr. Wood examined the shores of the small lake in the N. ½ of sec. 31, T. 63–10, and found them to be composed of the same syenite as is seen on Clearwater lake. At the southwest corner of this small lake he found fragments of mica-schist embedded in the syenite.

South branch of the Kawishiwi river in T. 63–10 and T. 62–10.

Going north from the river nearly on the line between secs. 5 and 6, T. 62–10, the syenite is seen to be cut by irregular small dykes or branching veins of a hornblende rock (No. 349) similar to that mentioned above (No. 343). These veins cut the syenite in every direction and their outlines are very sharp and distinct, especially on weathered surfaces. The syenite here varies somewhat, and as a rule is darker colored than that seen elsewhere in this vicinity; it is represented by Nos. 347 and 348. The syenite on the river shore near the above mentioned section line is also some-

what finer grained and darker than is usual (Nos. 350 and 351). On the north shore of the river in the S. W. ¼ N. W. ¼ sec. 5, T. 62-10, is a rather coarse grained diorite (Nos. 352, 353 and 354); it is more than half made up of green hornblende, and the feldspar is white or grayish,—the rock thus standing in sharp contrast to the surrounding syenite. The relations of the two rocks were not seen here, but the diorite probably is the same as the hornblende vein rocks described above, although in this place the diorite may possibly represent a basic facies of the syenite.

No. 355, from the S. E. ¼ of N. E. ¼ sec. 5, T. 62-10, well represents the syenite in this immediate vicinity; it is a rock of medium grain, reddish in color, and composed of a flesh-colored to reddish feldspar and hornblende; the latter makes up about one-third of the rock. Going south along the river in secs. 5, 4 and 9, the syenite, as a rule, becomes finer grained and in some places holds biotite instead of hornblende.

At the north end of the portage, N. W. ¼ of S. W. ¼ sec. 9, T. 62-10, just at the water's edge, is an outcrop of medium grained hornblende granite (No. 356); the quartz makes up about one-fourth of the rock. This is evidently a part of the syenite of the region, but is the first seen that contains macroscopic quartz grains in any amount. About one-third way across the portage the coarse grained grey gabbro (No. 357) common to this region is seen. This was traced west of the portage to within 200 feet of the syenite, but low ground with no exposures intervened between the two rocks. Here the syenite is fine grained and micaceous, as is shown by Nos. 358 and 359, the former being more properly a biotite granite. The syenite is cut by small dykes or veins of a fine grained red aplite (No. 360) composed almost entirely of a red feldspar and quartz. The gabbro retained its coarse grained character as near to the syenite as it was found.

The east side of the rapids, in S. W. ¼ sec. 9, T. 62-10, was carefully examined in order to study the relations of the syenite and gabbro, but nothing conclusive was seen. The syenite here is shown by Nos. 361 and 362, both rather fine grained and micaceous. Between the syenite and gabbro were found Nos. 363 and 364, the former partaking of the characters of the syenite and containing large quantities of a dark mineral, probably hornblende; the latter is finer grained and very dark in color. There were no continuous exposures connecting the syenite and gabbro. At the foot of the rapids I found several angular blocks, apparently not far removed from their original position, of a fine grained purplish rock, prob-

ably a porphyrite (No. 365). Mr. Wood examined the west side of the rapids, but could not find the gabbro and syenite near each other.

The west shore of the river in secs. 34, 35 and 26, T. 63–10, is made up of the ordinary syenite, which varies somewhat in the amount of hornblende it contains, as seen in Nos. 366 and 367. No. 366 is quite dark in color and the hornblende makes up more than one-half of the rock,—this facies, however, is exceptional. No. 367 is much lighter colored and is at least three-fourths composed of feldspar. No. 368, from the S. W. ¼ of sec. 34, fairly shows the syenite along this shore; it is composed of flesh-colored to red feldspar and black hornblende, the latter making up perhaps one-third of the rock. This rock is of a medium coarse grain. In section it is seen to be a granitic aggregate of orthoclase, hornblende and quartz. The orthoclase is gray and usually shows a cloudiness due to alteration; a few of the grains show polysynthetic twinning lamellæ. The hornblende is the ordinary green, highly pleochroic variety, and is completely allotriomorphic; it has altered in some places to chlorite, but elsewhere appears to be quite fresh. Quartz is scattered through the whole section, but is not noticeable macroscopically; it presents the characters of ordinary granitic quartz. It occurs oftentimes in polysomatic areas, and a large number of the grains show decided undulatory extinction. The quartz makes up less than ten per cent. of the whole rock. Apatite, sphene and magnetite are the accessory minerals; they all occur in only small amount. The apatite is in both short, stout and long, slender prisms. The sphene and magnetite show no characteristic crystal outlines.

Careful search was made for mica-schist along this shore, but no trace of it was found.

North branch of the Kawishiwi river in T. 63-10 and sec. 19, T. 63-9.

Mr. Wood went south from the river about on the west line of sec. 31, T. 63-10, for about half a mile. He reported mica-schist (No. 318) all the way, but in a few places, especially just south of the river, a green schistose rock (No. 319), probably a condition of the greenstone, was seen. From this section line he went northeast to the bay in the S. E. ¼ of S. W. ¼ of sec. 30, but saw no rock in situ except the mica-schist.

The little promontory on the south side of the river in the N. E. ¼ of S. W. ¼ sec. 30 is made up of red syenite (No. 320). This is a rather coarse grained rock and in some places it shows a dis-

tinct gneissic arrangement of the feldspar and hornblende. It is cut by a dyke of a dark hornblendic rock (No. 321); this dyke is vertical and varies from ten inches to two feet in width; it runs a little south of east and was traced for fifty feet. The west end of the portage across this promontory is in the mica-schist, but the line between the schist and syenite soon crosses the portage and runs a little south of the bay in the S. W. ¼ of S. E. ¼ of sec. 30. The two rocks were seen in actual contact just north of the portage; there was no transition from one to the other, the line between them being quite distinct. The syenite was finer grained and grayer in color near the contact; this is shown by Nos. 322 to 325 which were taken within a distance of two feet. The last one was touching No. 326 which is unmistakably part of the mica-schist. No. 327 is the mica-schist near to the last and No. 328 represents it a few feet from the seyenite. The line of contact was vertical and rather irregular, the syenite usually followed the direction of the schistosity, but in some places broke across it for a few inches. On the portage a few loose blocks were seen which showed both rocks in sharp contact (No. 329); however, it is not certain that these blocks had not been moved some distance.

The west shore of the river in the E. ½ of sec. 30 is almost all syenite, but about the center of the shore line some mica-schist is seen mixed with the syenite. The latter extends in vein-like branches into the former and also encloses pieces of it. Mr. Wood went from this place west to the stream that enters the river in the S. E. ¼ of N. W. ¼ sec. 30 and reported syenite all the way. He also found a fine grained diorite dyke (No. 330) in the syenite; this ran north and south, was ten feet in width and was traced for sixty feet. He also reported many inclusions in the syenite, of which Nos. 331 and 332 are samples; the former is a dark, rather fine grained diorite, the latter a fine grained silicious schist.

At the rapids in the S. E. ¼ of N. E. ¼ sec. 30 the river flows over angular syenite fragments. On the east shore of the river in the same $\frac{1}{16}$ section mica-schist and syenite are seen in contact. There is not as sharp a line here between the two rocks as at the above described locality; the change from one to the other occurs within one or two inches; Nos. 333 to 336 represent this change, the first three of these were taken within a distance of three inches.

The point in the N. E. ¼ of sec. 26 is made up of the ordinary coarse red syenite of the region, but on the north side of this point, about the center of the section, is a dark, rather coarse grained diorite (No. 369). Macroscopically this is seen to consist

of hornblende and a white feldspar, the former in larger amount than the latter. Under the microscope the feldspar is seen to be very highly altered and in only a few places is it fresh enough to show traces of polysynthetic twinning; the hornblende is of the ordinary green variety and is extensively changed to chlorite and some few flakes of biotite. The relation of this diorite to the syenite of the region was not determined, but the impression is that this is a basic facies of the syenite. The diorite is cut by a fine grained trap dyke (No. 370) and also by a light reddish fine grained granite (No. 371). The last appears in quite an amount and extends along the south shore of the river as far as the west end of the island in the S. E. ¼ of N. W. ¼ sec. 26. A short distance beyond this the diorite is seen in contact with a fine grained gray granite (No. 372), which is probably a part of the same rock as No. 371. The diorite here (No. 373) has both red and white feldspar and seems to be rather intermediate between the ordinary syenite and the diorite described above (No. 369), thus indicating the probable identity of the two rocks. No. 374 shows the two rocks (Nos. 372 and 373) in contact; the line is very sharp and distinct, but at this place nothing was seen to indicate the relative ages of the two. The diorite continues along the shore in the S. W. ¼ of sec. 26, and in some places becomes lighter colored as shown by No. 375. In a westerly facing diorite cliff (N. W. ¼ of S. W. ¼ sec. 26) are three small dykes, about a foot wide, running diagonally up the cliff towards the north. No. 376 was taken from one of these dykes; it is a dark, rather fine grained rock, composed almost entirely of hornblende.

At the southern end of the bay in S. W. ¼ of S. W. ¼ sec. 26 the syenite again occurs. It is here represented by No. 377, which has most of its hornblende altered to chlorite. At this place a small piece of finely laminated gneiss (No. 378) was found enclosed in the syenite. The western shore in the E. ½ of sec. 27 is composed of the syenite similar to No. 377.

Just north of the river on the line between sec. 21 and 22 is a low outcrop of aphanitic greenstone (No. 379). It is much cracked and fissured and shows an indistinct, coarse schistose structure, which is vertical and runs east and west. Farther north from the lake on the same section line is an outcrop of very massive greenstone (No. 380), which is of coarser grain and grayer color than that last mentioned. This is seen in contact with a quartz porphyry (No. 381) which holds a few quartz crystals, many white feldspars and numerous small pyrite grains in a grayish groundmass. The contact line between the two rocks is sharp, stands

vertical and runs north and south. Only a small area of the quartz porphyry was exposed; it probably forms a dyke in the greenstone. Continuing northward on this section line for about three-quarters of a mile from the river, several ridges of massive greenstone are crossed. No. 382 shows the most massive and coarse grained condition of this greenstone.

On the north shore of the river, just west of the line between secs. 27 and 28 are several outcrops of a fissured greenstone similar to No. 379. Farther west on the same shore and just east of the portage is a large outcrop of a finely laminated graywacke-like rock (No. 383); it is in some places much coarser grained, as shown by No. 384. The strike is N. 75° E., and the dip from 75° to 80° S. On the north side of the river and between the portage and the head of the rapids (N. E. ¼ of N. E. ¼ sec. 28) a rock similar to the last, except that it is more massive in appearance, is found. Here on some of the weathered surfaces an indistinct vertical lamination is seen; this varies somewhat in direction but the general trend appears to be about 25° E. of N. Nos. 385 and 386 represent the rock at this place. This laminated rock belongs to a fragmental series which is here in contact with syenite. This series is made up of rocks which are very often graywackes and often mica-schists, with all intermediate stages; and there are also some facies that are more like coarse grits, silicious schists and even sericitic schists. These different facies constantly intergrade. For convenience the term "graywacke-like rock" will be used for the finer grained and less crystalline rocks of this series. Mica-schist and gneiss will bo used to refer to parts of the same series which are more highly altered.

A short distance from the east end of the above mentioned portage rock similar to Nos. 383 and 384 is found; here the lamination is distinct; the strike is 72° E. of N. and the dip S. 85°. A little further west the syenite (No. 387) occurs. It has a vertical gneissic structure which is very evident on weathered surfaces; this strikes on the average about 70° E. of N., but varies as much as 15° either side of this direction. This syenite occurs directly in the strike of the last mentioned outcrop of laminated graywacke-like rock.

About half way across the portage is a soft fissile greenstone or greenstone schist (No. 388). In this is a series of parallel veinings which coincide with the direction of the cleavage planes in the rock; both stand vertical and strike N. 80° E. A few feet south of this the ordinary syenite is seen. There is almost a continuous exposure between the two rocks, and samples illustrating the

change from one to the other were taken. No. 389, from eight inches south of 388; 390 was eight inches further south; then within a foot came 391 and 392; two feet further was 393, and three feet from this 394, which grades into the ordinary syenite represented by No. 387. The change from the greenstone schist to the syenite is first noticed by a small amount of red feldspar in the greenstone; the feldspar gradually increases in amount and the green material decreases until the ordinary syenite is reached. The schistose structure in the greenstone and the gneissic structure in the syenite are parallel and grade into each other as the two rocks intermingle. One hundred feet north of this place is a low southerly facing bluff of greenstone, much cracked and fissured. On the weathered surfaces it shows a series of reddish, vertical veinings whose average strike is N. 70° E, and almost at right angles to this are two nearly parallel systems of joints which cut the rock into small elongated diamond-shaped areas.* Specimen No. 395 shows this jointing fairly well.

Further west on the portage trail more of the greenstone is seen. Then the syenite appears again, and beyond this, not more than 200 yards east of the west end of the portage, the graywacke-like rock again appears. It has the distinct lamination seen before and strikes N. 60° E.; the dip varies from 80° towards the north of this line to 70° on the other side. The syenite occurs on the portage directly in the strike of this rock and not more than 150 yards east of it. The laminated rock is seen in contact with the syenite, which here lies north of it, about 50 yards north of the stream. It is here shown by No. 395A, which has considerable sericitic material developed in it. Eight inches north of this occurs the actual contact between the two rocks; the hand specimens No. 396 show this. The line between the two is distinct, but the syenite holds considerable of the material of the other rock. Six inches north of this the syenite is shown by No. 397; seven inches beyond by No. 398; eighteen inches from this by No. 399, and four feet further north it has its usual character and appearance, as shown by No. 400. At this place the contact was along the strike of the laminated rock and there is nothing to show their relative ages. The syenite now extends northward for thirty feet, where it disappears under the soil as it does just to the west of this place. Boulders of massive greenstone occur just north of the syenite, but the greenstone is not seen certainly in place until a low ridge of it (No. 401) is reached fifty feet north of the syenite.

*Compare the diagrams of jointing and schistose structure in the greenstones of the Menominee river, Michigan; Bul. 62, U. S. Geol. Survey, p. 128.

The high ridge, running east and west through the N. ½ of N. W. ¼ sec. 28, is composed of massive greenstone. In places it is cut by irregular branching dykes of gray quartz porphyry. These dykes vary from an inch up to more than a dozen feet across. The principal and largest one runs about east and west along the southern edge of the top of the ridge and varies considerably in width. The contact between the porphyry and the greenstone is sharp and there is no intermingling of the two rocks. At the contact the greenstone does not appear to be much changed except that it is more broken and fissured. Pieces of the greenstone are included in the dyke. Nos. 402 and 403 represent this porphyry; the former was taken within three inches of the edge of the dyke, and the latter about four feet from the edge. This rock has a grayish groundmass in which are imbedded a few quartz grains and numerous flesh-colored and blood-red feldspars The quartz is more plentiful near the edge of the dyke (No. 402). In places the rock contains minute cavities, apparently formed by the weathering out of certain constituents of the rock. Under the microscope the rock is seen to have a micrograniti
c groundmass of rather variable grain. In this are feldspars of all sizes up to pieces over a quarter of an inch in length. The crystal outlines of the feldspars are not usually distinct and most of them show no planes at all, being pieces with irregular outlines. Many of the feldspars show polysynthetic twinning lamellæ, and a large number do not. Alteration to sericite is quite common, and in some cracks and areas of considerable size in the groundmass sericite has been developed in large amount. Secondary calcite is also present. No distinction between the flesh-colored and the blood-red feldspars can be made in ordinary section,—they both appear colorless; and as yet no oriented sections of the two kinds have been studied; they appear very distinct in the hand specimen. Scattered through the rock are colorless to greenish secondary needles of chlorite or hornblende. A few areas of green hornblende, more or less altered, also occur, but it is not possible to say whether or not this hornblende was the form of the original ferro-magnesian constituent of the rock. Sphene and apatite are present in small amount. Large quartz grains are not present in the sections examined, although macroscopic grains are often seen in the hand specimens collected.

On going south from the stream into the S. E. ¼ of N. W. ¼ sec. 28, the graywacke-like rock is seen showing the characteristic lamination. Soon this rock begins to grow more crystalline, and this character becomes more and more pronounced as one proceeds southward. No. 404 shows this more crystalline facies, but in this

the lamination is still distinctly preserved. Interbedded with this are beds of a less crystalline character, as shown by No. 405, which is very similar to the mica-schist found to the west in sec. 30, already described. Other facies of this rock are shown by Nos. 406, 407 and 408, which are all completely crystalline. The first of these is a distinct gneiss, and the latter show no gneissic structure, even on the most favorable weathered surfaces. Macroscopically these three specimens are seen to be composed of quartz, a light colored feldspar, biotite and some little hornblende. These rocks, while completely crystalline, can in no wise be separated from the less crystalline facies and the graywacke-like rocks already mentioned several times. They are interbedded in bands from one-half inch to two feet in thickness,—the more crystalline always in the thicker beds. They seem to grade into each other across the the strike, and in some places the less crystalline is replaced along the strike by the more crystalline,—the former fading out into the latter. The most crystalline facies contain many black lens-shaped pieces of black diorite (No. 409); these pieces are composed mostly of hornblende with some little white feldspar. The exposures above described extend south from the stream for a quarter of a mile, and beyond this is low swampy ground with no exposures. The strike at the most southerly place seen was N. 70° E., and the dip vertical or very steep toward the south.

A narrow belt of syenite (No. 410) extends along the north shore of the river in the N. ½ of N. E. ¼ sec. 29. Just north of the syenite is a range of greenstone hills running east and west. In some places the two rocks were seen within fifty feet of each other, but at no place was the junction between them seen. The syenite rises in a bold bluff at the portage in the W. ½ of N.W. ¼ of N.E. ¼ sec. 29. About one-quarter of a mile east of this portage the greenstone is cut by an irregular dyke of gray quartz porphyry (No. 411). This dyke where examined is three to ten feet wide and has a general east and west direction. It was also seen, but not visited, in the greenstone both east and west of this locality. This dyke is probably a westward continuation of that already described from the N. ½ of N. W. ¼ of sec. 28.

Coming south from the river about on the line between secs. 28 and 29, the laminated rock and gneiss similar to that described above (Nos. 404 to 408) are seen in many exposures. About one-third of a mile from the river the syenite suddenly appears. It was first seen as a belt, 100 feet in width, running parallel with the gneiss which appears on both sides of it. The gneiss preserves its usual character and distinct alternation of different bands clear

to the syenite. No. 420 shows this rock within a few feet of the syenite. Nos. 421 and 422 come from within three and one inches respectively of the syenite; the latter is some more coarsely crystallized and contains many distinct hornblende grains and some red feldspar. No. 423 shows the two rocks together; the line between them is quite sharp and distinct. No. 424 is the syenite just beyond No. 423; it is quite gneissic in structure. The strike of the gneiss is N. 60° E., and the gneissic structure of the syenite stands parallel to this; the dip is 5° either side of the vertical. In some places the line between the two rocks, instead of running with the lamination, runs across the strike for a few inches. In other places the syenite is more completely granitic in structure, as shown by No. 425. A short distance south of this the gneiss is much contorted and is cut by stringers, two to three feet across, of the syenite; some of these run with the lamination of the gneiss and others cut across it. There is no gradation from the gneiss to the syenite; the line between the two is clear and sharp. Further south the syenite becomes the prevailing rock, and in many places it holds lenticular masses of the gneiss.

On the south shore of the river just west of the line between secs. 28 and 29 the laminated rock is seen. Still further west, about half way from this section line to the rapids, which are about in the N. W. ¼ of N. E. ¼ sec. 29, the syenite again appears, but less than 200 feet south from the shore it comes in contact with the laminated rock. The junction here is along the strike of the laminated rock and the syenite was not seen cutting across the strike. The line between the two was distinct and easily seen on weathered surfaces. From the rapids just mentioned west to the east line of sec. 30 the laminated rock occurs on the south shore and a high bluff of it is seen just south of the river on this section line. The little bay in the N. E. ¼ of N. E. ¼ sec. 30 has syenite on its south and greenstone on its north shore.

Mr. Wood went south from the river about on the line between secs. 29 and 30. He found the laminated rock in place all the way until nearly half a mile from the river, when the syenite was seen. No. 426 shows the laminated rock, which here approaches a mica-schist, and No. 427 is more accurately a mica-schist. This latter facies of the rock was that most commonly seen, but that seen nearest the syenite was more like No. 426.

The north shore of the river, in the N. ½ of N. W. ¼ sec. 29, is made of greenstone, but the syenite comes in at the water's edge just west of the portage in the eastern edge of this quarter section. I went north from the river on the west line of this section for one-

third mile, but found no rock except massive greenstone, of which several exposures were seen. About one-fourth of a mile east of this line and just north of the river the greenstone is cut by a dyke of reddish fine grained rock (No. 428) resembling a syenite porphyry. The dyke has an east and west direction and was traced for fifty feet. The sides of it were covered by soil, and as far as seen it was not more than ten feet wide.

The point on the south side of the river, in the W. ½ of N. W. ¼ of N. W. ¼ sec. 27, is made up of the laminated rock* and is well shown by the specimens already described,—Nos. 383 to 386. The strike varies from N. 30° E. to 45 E., and the dip from 75° to 80° S. E. Along the shore just west of this point the laminæ are much contorted. The point on the north side of the little bay in the same $\frac{1}{16}$ section is also made of the same rock. The small island in this bay is composed mostly of the syenite, but the northern side has a little of the laminated rock. Near the syenite this rock changes, becoming more crystalline and acquiring some reddish feldspar (Nos. 429, 430 and 431); but this condition exists only within a few inches of the syenite, in fact the syenite, as shown by No. 432, is seen within six inches of the above specimens. The junction between the two is easily seen as a pretty distinct line on weathered surfaces. Small pieces of the laminated rock were found in the syenite; No. 433 is from one of these. On the shore just east of this the syenite is intimately mixed with the laminated rock; still the line between the two is distinct and the syenite seems to have enclosed pieces of the other rock. In one place the syenite holds a small area of a dark compact mica-schist (No. 434), which is really part of the laminated rock, and shows lamination in favorable places. No. 435 shows this rock and the syenite together; they are marked off from each other by a sharp line.

The laminated rock is again seen on both points of the promontory in the N. E. ¼ of N. W. ¼ sec. 27, but the syenite appears on the western shore of the little bay in this $\frac{1}{16}$ section and also on the south and east sides of it. At the southeastern corner of this bay the rock has a decidedly schistose structure and there are alternating bands of schistose syenite (No. 436) and rock similar to Nos. 429 and 431 which appears to be an altered condition of the laminated rock; this is shown by Nos. 437 and 438. These bands of syenite and Nos. 437 and 438 vary from one inch to one foot in width, and they are parallel to the schistosity of both rocks. This

*This is the rock described by N. H. Winchell in the 15th (1886) Annual Report, p. 352, under No 989.

is N. 40° E. and the dip nearly vertical. Nos. 437 and 438, while still retaining considerable of the sericitic material, have large quantities of reddish feldspar and some hornblende developed in them. Between these bands and almost always running parallel with them are vein-like forms of a fine grained pinkish granitic rock (No. 439) holding flesh colored feldspar phenocrysts. These veins vary from one to ten inches across and rapidly change their thickness in a short distance. They are also frequently faulted.

On the north shore of the river in the N. W. ¼ of N. W. ¼ sec. 27 the laminated rock is found, and just north of this is a belt of syenite 150 feet wide, separating this rock from the greenstone. The junction of the syenite and laminated rock was seen in one place; the phenomena at the contact are the same as those already described under Nos. 395A to 400. The line between the two rocks runs parallel with the strike of the laminated rock and is quite easily distinguished. The syenite is also seen in contact with the greenstone; the change from one rock to the other occupies one or two feet and is essentially the same as that described above under Nos. 388 to 394. In some places in this vicinity the syenite, especially when in close proximity to the greenstone, becomes very schistose, as is shown by No. 440, which is dark colored and shows a decidedly gneissic structure; but generally in this $\frac{1}{16}$ section the syenite is dark, massive and chloritic (No. 441). The syenite extends along the north shore from this place to the small bay in the S. E. ¼ of S. E. ¼ sec. 22. It forms only a narrow belt between the river and the greenstone ridge just north of it. Along this shore the syenite varies from a massive state, similar to No. 432, to a more chloritic (No. 441) and schistose condition (No. 440).

The island in the middle of the river just north of the west end of the promontory, in the N. E. ¼ of N. W. ¼ sec. 27, is composed entirely of the graywacke-like rock. The lamination is very pronounced and the strike is quite constant, being about N. 63° E.; the dip is nearly vertical. This strike would carry the rock into the north shore of the river less than a quarter of a mile east of the island, but there the syenite is seen and there is no sign of the graywacke-like rock.

On the little bay, in the S. E. ¼ of S. E. ¼ sec. 22, the graywacke-like rock is again seen just north of the south line of this section. The lamination is very distinct, and, while varying some, has a general northeasterly strike. A short distance south of this the syenite appears and extends along the north side and to the end of the point which makes the southern side of this bay. The gray-

wacke-like rock makes up the southern half of this point; it is much twisted and crumpled. Its junction with the syenite was seen in one place; the line between this (No. 442) and the syenite (massive and similar to No. 432) was distinct. Just at the contact the graywacke-like rock showed distinct lamination in but a few small areas and here it faded out in a short distance. Away from the contact the lamination was very evident, though much twisted, and the rock was more like Nos. 383 and 384. The massive syenite is seen again on this point just east and west of the line between secs. 26 and 27.

In the N.W. ¼ of N. W. ¼ of N.W. ¼ sec. 26, the syenite is found on the shore. Just north of it the graywacke-like rock is seen; this becomes somewhat more crystalline, as shown by Nos. 443 and 444, and it seems to pass gradually into No. 445, which is a distinct gray gneiss. However, this gneiss was seen to hold sharply defined lenticular pieces of rock similar to some facies of the greenstone. No. 446 shows the gneiss and part of one of the lenticular pieces in it. The junction of the gneiss and syenite was not seen. The syenite here presents a decidedly gneissic structure, but this grades into the more massive facies within two or three feet. The phenomena here seem to be about the same as those described under Nos. 404 to 409; the gneiss (No. 445) is apparently a changed condition of the graywacke-like rock, although in some places the two are separated by a sharp line. Fifteen feet north of this the graywacke-like rock again appears; it is nearly vertical, and, while bent in some places, there is a decided general strike of N. 60° E. At times the rock is similar to Nos. 383 and 384, and again like No. 443. This graywacke-like rock continues northward for about 200 feet and then the syenite occurs. The two are separated by low ground with no exposures.

The syenite continues northeastwardly along the northwest shore of this bay (N. ½ of N. W. ¼ sec. 26) for some distance, and in it is a band of the graywacke-like rock ten feet wide. This is sharply marked off from the syenite on each side, and is distinctly laminated, striking northeast. In some places this band is similar to No. 443, but the most of it is mica-schist, as shown by No. 447. On the north side of this bay hills of greenstone are seen in the N. W. ¼ of N. W. ¼ sec. 26. The greenstone and syenite were seen within fifty feet of each other, but the junction was not found. The syenite becomes schistose and chloritic near the greenstone, as has been described farther to the west. Within 300 feet of the greenstone the syenite holds irregular sharply outlined pieces of the

geenstone, which are from one to ten feet in diameter. On the weathered surfaces these pieces very closely resemble the greenstone in the hills just to the north, but on freshly broken surfaces the rock is seen to be slightly darker than the greenstone in the hills. No. 448 is from one of these pieces in the syenite. The greenstone in the hills near the syenite has a schistose structure, as shown by No. 449. This is twisted and somewhat irregular, but the general strike is N. 65° E., and the dip about vertical. The rock is lighter in color than the ordinary greenstone and contains some feldspar which weathers reddish. A short distance to the east the greenstone assumes the characteristic green color seen farther to the west, but the schistose structure does not altogether disappear. On the eastern side of the small point on the north shore of this bay the syenite occurs in a low outcrop. It is here in contact with the graywacke-like rock, but seems to enclose masses of this rock. The syenite here is mostly massive, but in a few places shows a gneissic structure which runs northeastwardly. There are pieces (a foot or so in length) of the graywacke-like rock enclosed in the syenite; most of these are facies of the rock approaching mica-schist. These pieces are mostly irregularly lenticular in shape and the lamination is parallel with their long axes, which usually lie in a northeasterly direction. Syenite occurs on the east shore of this bay.

The shores of the little bay which lies partly in the extreme southern part of sec. 23 are lined with syenite of the ordinary massive kind. About 100 yards north of the northwest corner of the bay is a hill of syenite which presents the schistose and chloritic character seen several times in close proximity to the greenstone. At the extreme eastern end of the bay the syenite is seen in contact with a dark diorite (No. 450), which is spotted by large blotches of hornblende. The contact line is sharp, as shown by No. 451, and neither of the rocks appears changed at the contact. The syenite is cut, on the eastern shores of the bay, by a coarse grained pegmatite (No. 452). This consists of large flesh-colored feldspars and small quartz grains, and often shows a true pegmatitic structure.

From this bay to the rapids, in the E. ½ of S. E. ¼ sec. 24, the north shore of the river has numerous outcrops of the ordinary massive syenite. No mica-schist or graywacke-like rock was seen along this shore, although special search was made for them.

On the south shore of the river, in the N. W. ¼ of sec. 25, there is a westerly facing gabbro cliff. On the face of the cliff was a small area, a foot square, of a reddish syenite bearing much biotite;

the specimen collected (No. 460) shows this rock and the gabbro. No other rock, except the gabbro, was found on the cliff. Just at the foot of the cliff was a large block of gray syenite (No. 461) and several small red syenite fragments (No. 462); these looked as if they had been broken off from the face of the cliff. This is possibly the line of juction between the syenite and the gabbro, but nothing more than above stated could be seen. The gabbro was the ordinary coarse grained facies.

The syenite of sec. 26 varies a little from that described from sec. 27. It is represented by No. 463, which is somewhat finer grained than the ordinary facies and is lighter in color, being more of a gray than a sed syenite, but on weathering it takes on a reddish color.

The river in the S. W. ¼ of sec. 19, T. 63–9, has two rapid channels around a small island, not shown on the township plat. The portage is along the south shore of the southern channel. At the east end of this portage gray syenite, similar to No. 463, occurs. Just beyond the portage and on the south shore of the island is a dark rock (No. 464) which seems to be intermediate between the gabbro and the syenite. It is a very compact rock of medium grain and uniform dark color, and on a freshly fractured surface shows in places yellowish color due to minute cracks; on weathered surfaces it has the appearance of the gabbro. This rock grades into the syenite (No. 467) through Nos. 465 and 466. The syenite was found at only one place, and that at the foot of a low cliff; the change from No. 464 to the syenite occupies two or three feet. This seems to be the junction of the gabbro and the syenite, but no true gabbro was found on the island, and it is not certain that No. 464 does represent the contact facies of the gabbro. Near the eastern end of the island gray syenite, shown by No. 469, is again seen. The ordinary coarse grained gabbro (No. 468) occurs on the south shore of the river just opposite this island, and on this shore no syenite was found. From this island the syenite continues along the west side of the river to the western end of the little bay in the S. E. ¼ of N. W. ¼ sec. 19, T. 63–9. The only exception to this is that on the south side of the point about the center of sec. 19, T. 63–9, the gabbro, similar to No. 468, is seen in a low outcrop. Thirty feet north of this gabbro is a gray rock (No. 470) which seems to be intermediate between the gabbro and the syenite. And 100 feet north of this the syenite is again seen. There is no continuous exposure between this syenite and the gabbro mentioned above. In places on a little island, which lies just off the end of this point, the syenite has a gneissic structure which stands about vertical and strikes N. 40° E.

On the north side of the bay, in the S. E. ¼ of N. W. ¼ sec. 19, T. 63–9, are many outcrops of a very fine grained, aphanitic grayish rock. It is shown by Nos. 471 and 472. This is apparently a facies of the greenstone.* It continues for an eighth of a mile, and probably much farther, north from the river. This rock continues along the north shore of the river for about a mile from this bay. On the line between secs. 19 and 20, a few rods back from the water (north shore of river), is an exposure of a fine grained massive diorite (No. 473). This was not, as far as seen, sharply separated from the rock shown by Nos. 471 and 472. Greenstone, or a rock intermediate between the greenstone and this diorite, was traced north on this section line for about a third of a mile.

Small lakes in T. 63–10, north of the Kawishiwi river.

Starting from the river, on the line between secs. 28 and 29, is a portage which runs north to a narrow lake, which lies in secs. 15, 16, 20 and 21. The portage crosses several greenstone ridges. These present an extremely massive appearance; this is especially noticeable towards the north end of the portage. No. 412 fairly represents this greenstone; it is a dark green aphanitic rock; it was taken from an outcrop on the portage about an eighth of a mile north of the section corner. Greenstone of the same massive kind, with no evidence of schistosity or lamination, extends along the shores of this lake in section 20. At the west end of the lake a dyke of gray granite porphyry (No. 413) cuts the greenstone. The general direction of the dyke is east and west, but not enough of it was exposed to show the exact width, though this is probably not more than fifteen feet In the rock are many quartz and feldspar phenocrysts, some of the latter being a half an inch in length. Macroscopically this rock closely resembles No. 417, which will be described more in detail. A small island, in the W. ½ of S. W. ¼ of N. W. ¼ sec. 21, also shows more of this granite porphyry. Greenstone extends along the north shore in sec. 21, but on the point, in the N. W. ¼ of N. E. ¼ of the same section, there is a bluff of a fine grained red-weathering siliceous rock (No. 414), which is probably a facies of quartz porphyry. Just north of this bluff the greenstone occurs, but the junction of the two rocks was not seen. Greenstone appears to make the rest of the lake shore, but on the east side of the little bay (south shore of the lake), in the W. ½ of N. E. ¼ sec. 21, a dyke of quartz porphyry is seen cutting the greenstone. This dyke is fifty feet wide, stands vertical and strikes a lit-

*This locality has been already fully described in the 15th (1886) Annual Report, pp. 345–347.

tle north of west; this strike would carry it directly into the rock No. 414, mentioned above, which is probably a continuation of this dyke. The contact between the greenstone and quartz porphyry is sharp and distinct, and the former does not seem to be especially altered near this line. The centre of the dyke is much coarser grained than the edge. No. 415 shows the greenstone within two inches of the dyke; No. 416 is the quartz porphyry two inches from the edge of the dyke, and No. 417 is the same from the centre of the dyke. The quartz porphyry (No. 417) is of a general pinkish color; it contains many quartz and feldspar phenocrysts, the latter being white and flesh-colored. A few small specks of a dark mineral are also present. The rock seems to the unaided eye to have no unindividualized ground-mass, but microscopically the rock shows a decided microgranitic ground-mass of rather small but irregular grain. Imbedded in this are numerous feldspar phenocrysts of all sizes up to those nearly half an inch in length. Most of these feldspars show their crystallographic outlines on all sides, but some few appear as fragments partially bounded by crystal planes. Zonal structure is quite common, and about half of the individuals show polysynthetic twinning lamellæ. Quartz individuals of good size are also present, but are not nearly as abundant as the feldspars. The quartzes are all corroded and show no crystal faces, and they frequently have large embayments filled in with the ground-mass. Some of the quartz shows undulatory extinction, but otherwise the rock gives no evidence of having been subject to pressure. Scattered through the ground-mass are irregularly outlined green areas composed of chlorite and epidote. What the original ferromagnesian constituent of the rock was is now impossible to determine. A few small acute rhombs of sphene are also present. The rock is properly a microgranite. Rock No. 416, from the edge of this dyke, presents the same appearance as that just described, except that the ground-mass is of some finer grain and the feldspar is mostly in fragments.

The shores of this lake seem to be made entirely of greenstone, cut in a few places by quartz porphyry dykes. The greenstone is very massive and in no place where examined shows any evidence of lamination or schistosity. It is well represented by No. 412, from the portage south of the lake, and by No. 418, from the north shore on the line between secs. 16 and 21.

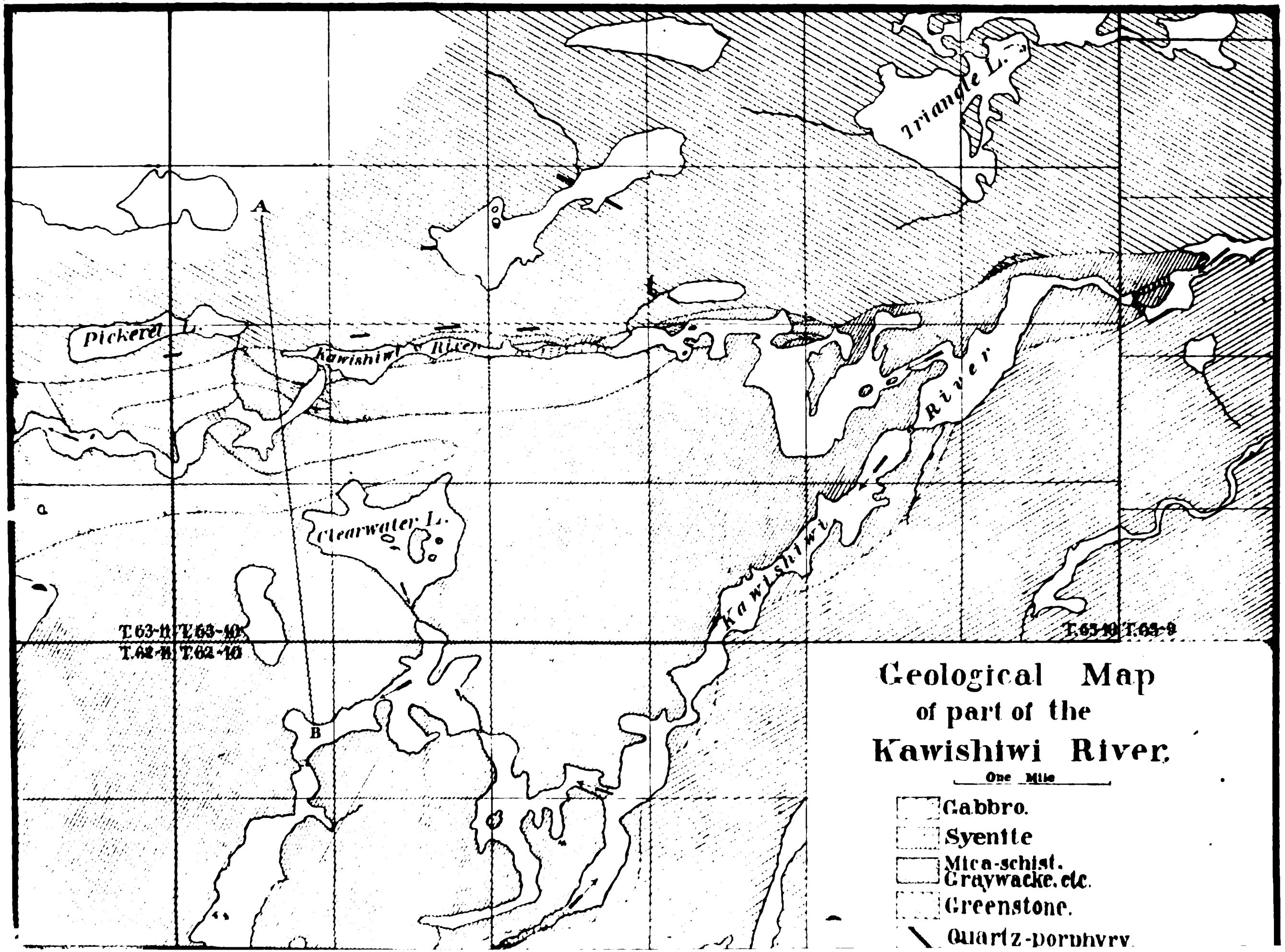
From this lake there is a trail running north on the line between secs. 15 and 16 to a small lake lying in the N. W. ¼ of sec. 15 and the N. E. ¼ of sec. 16. No rock is *in situ* along this trail, but at the shore of the latter lake the greenstone is in place. The shores

of the lake, as far as could be seen from the meander corner, were lined with rock which had all the appearance of greenstone. On this trail and a few yards south of the lake is a low hill, the north side of which shows many angular fragments of rock. This rock is made up of alternating bands of compact black slate and bands of almost pure magnetite. These bands vary from one-eighth of an inch to an inch in thickness. They are very regular, and on the whole the rock is very similar to some Kewatin ore described from Ottertrack lake.* The fragments of this rock were of all sizes up to those three feet in diameter, and while no pieces were exactly *in situ*, still there can be no doubt but that the rock is *in situ* just below these fragments. No. 419 represents this rock.

From the north shore of the Kawishiwi river, in the N. E. ¼ of S. W. ¼ sec. 24, a portage runs northwesterly to the southeast corner of Triangle lake. This lake lies in secs. 13, 14, 23 and 24, T. 63–10. Just north of the river the portage crosses a low ridge of gneissic syenite, and a short distance beyond is a ridge of the graywacke-like rock. This latter is shown by Nos. 453, 454 and 455. Just east of the portage this ridge is seen to better advantage; here the strike is N. 60° E., and the dip vertical. Fifty feet north of this ridge massive greenstone (No. 456) is seen. The two rocks were traced within thirty feet of each other, but the junction was covered by soil. Beyond this more greenstone ridges are seen on the portage; usually the rock is massive in appearance, but it sometimes shows an indistinct schistose structure which stands vertical and strikes about northeast. About half way over the portage is a ridge of greenish, finely laminated rock, represented by No. 457. The lamination is very distinctly seen on weathered surfaces, and in places the rock is decidedly slaty. The strike is N. 65° E., and the dip vertical. This rock seems to be a facies of the greenstone. Beyond this rock greenstone is seen in several places on the trail before reaching Triangle lake. Several outcrops on the east shore of this lake were examined, but the rock was all greenstone.

From the northeast corner of Triangle lake a portage of a few yards leads to Northwest lake, which lies in secs. 11, 12, 13 and 14, T. 63–10, and secs. 7 and 18, T. 63-9. On the south side of a small island, in the N. E. ¼ of N. W. ¼ sec. 13 (Northwest lake), is a low outcrop of altered quartz porphyry (No. 458). This rock has the ground-mass almost entirely changed to a sericitic condition, but it still contains many porphyritic quartzes and large pinkish feldspars. Some of the feldspars are an inch long; they can be read-

*17th (1888) Annual Report, pp. 112-113.


Geological Map
of part of the
Kawishiwi River.
One Mile
Gabbro.
Syenite
Mica-schist.
Graywacke, etc.
Greenstone.
Quartz-porphyry.
Triangle L.
Pickerel L.
Kawishiwi River
Clearwater L.
Kawishiwi River
A
B
T. 63-11 T. 63-10
T. 62-11 T. 62-10
T. 63-10 T. 63-9

ily broken out of the ground-mass. and they show complete crystal outlines. The sericitic ground-mass gives a rough schistose structure to the rock; the strike of this is N. 60° E., and the dip about vertical. The south shore of this lake was examined in several places and the greenstone was the only rock seen; this extends to the extreme eastern end of the lake in the N. E. ¼ of sec. 18, T. 63–9. On the north side of the lake, in the N. E. ¼ of N. E. ¼ sec. 13, T. 63–10, the greenstone has a peculiarly mottled appearance. This is shown by No. 459. It is due to numerous black blotches, apparently of hornblende.

Geological map of part of the Kawishiwi river.

The distribution of the different rock masses in that part of the Kawishiwi river, described in the foregoing field notes, is shown on the accompanying map. Five distinct rock types are present, the characters and relations of which have already been briefly given. The gabbro is the most recent; it covers parts of the older rocks and is very extensively developed just to the south of the area of this map. The syenite is older than the gabbro, and is younger than the greenstone and mica schist, both of which it cuts in a truly irruptive manner. The mica-schists, graywackes, etc., stand vertical and have a general E. N.-E. strike; they belong to what has been mapped as the Vermilion series, but there seems to be good reason for putting all of this type of rocks, in the area of this map, into the Keewatin. The greenstone is presumably of

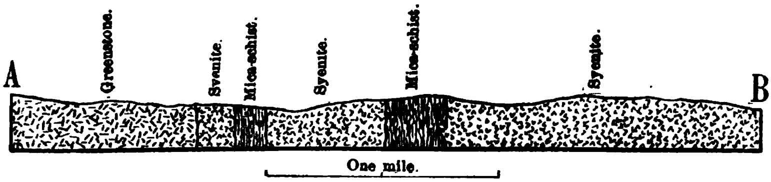


Fig. 3. Section along the line A B, of the geological map of part of the Kawishiwi river.

Keewatin age and is probably younger than the mica-schists, graywackes, etc. Quartz porphyry dykes are found cutting the greenstone in several places, but they have not yet been seen in the other rocks in this immediate vicinity.

B. SNOWBANK LAKE AREA.

The outlines of the granite on this lake were traced much less minutely than those of any other of the areas visited. In fact but a short time was spent in this vicinity, and the only things to which much attention was given were the nature of the granite and its relations to the surrounding rocks.

Portage from the Kawishiwi river to Snowbank lake.

This portage starts from the river in the N. E. ¼ of N. W. ¼ sec. 15, crosses the S. E. corner of sec. 10 and reaches Snowbank lake at its southwestern corner in the S. E. ¼ of N, E. ¼ sec. 11; all in T. 63–9. No rock but the ordinary coarse grained gabbro was seen until after reaching the S. W. ¼ of sec. 11.* About one-third of a mile east of the line between secs. 10 and 11 is a low ridge of coarse pinkish syenite (No. 474). A short distance beyond this is an outcrop of fine grained red syenite (No. 475), and farther on, just to the right of and on the portage, is a coarse pink syenite (No, 476) much resembling No. 474. A little farther is a dark colored rather fine grained diorite (No. 477), and just beyond this is another still finer grained diorite, which continues for a short distance, where it is cut by veins of a fine grained gray to reddish syenite (No. 478); at this latter place the finer diorite is represented by No. 479. On the north side of the same ridge in which the last two rocks occur a gray porphyritic syenite (No. 480) is seen. The relation of this to the other rocks could not be determined. Farther on and a short distance to the left of the trail is a low ridge of this same gray porphyritic syenite, here represented by No. 481. There are thus seen on this portage several apparently distinct kinds of syenite, but the relations between them were not ascertained, as there were but few outcrops and in no exposure did two of these syenites occur together.

Snowbank lake.

On the west shore, in the N. ½ of N. E. ¼ sec. 11, T. 63–9, a fine grained syenite (No. 482) in seen; this is quite similar in appearance to Nos. 480 and 481. Farther north syenite is again seen on the shore; here it is coarser grained and not at all like No. 482. This coarser grained syenite extends along the west shore into the northwest corner of the bay in the S. ½ of S. E. ¼ sec. 2, T. 63–9. Here it is represented by Nos. 483 and 484; the former is a dark red syenite of medium grain, and the latter is of lighter color, contains less hornblende and is the facies of the rock that is most common at this locality. Just off the point, which is in the N. W. ¼ of S. E. ¼ sec. 2, T. 63–9, is a small island made of a coarser facies of the same syenite (No. 485). This is cut by veins, of all sizes up to three feet across, of a dull reddish rather coarse grained syenite (No. 486) made up almost entirely of feldspar; the other constituent is in small amount and seems to be epidote. The point crossed

*For descriptions of the gabbro and associated rocks on this portage, in secs. 10 and 15, see the 17th (1888) Annual Report, p. 120.

by the line between secs. 35 and 36, T. 64–9, is composed of dark diorite of medium grain (No. 487); this appears in the form of a dyke, 100 feet or more in width. It runs about north and south. The syenite was seen just east of this point and also along the shore west of it; here the syenite is quite coarse grained and contains much biotite (No. 488). The point on the south shore, in the S. E. ¼ of N. W. ¼ sec. 35, T. 64–9, shows syenite of a rather fine grain (No. 489).

The bay which runs south along the line between secs. 34 and 35, T. 64–9, shows no outcrops along its shores. And on going west a short distance, near the township line, no rock was seen *in situ*.

On the west shore, in the N. E. ¼ of N. E. ¼ sec. 34, T. 64–9, a shore distance north of the portage which runs to Flash lake, is a large bluff of fine grained diabase. Farther north on the west shore of the narrow bay in the S. E. ¼ of S. E. ¼ sec. 27, T. 64–9, the fine grained greenish diabase, here represented by No. 489A, is cut by an irregular dyke of reddish porphyry (No. 490). This dyke is from two to five feet wide and was traced for at least thirty feet. Another small mass of this same rock was seen near by, but it was exposed only in one place. This porphyry (No. 490) has a reddish to purplish aphanitic ground-mass, in which are porphyritic crystals of red feldspar and small areas of chlorite. Under the microscope the ground-mass is seen to be microgranitic in structure and apparently composed of quartz and feldspar. The feldspar phenocrysts are more or less altered and the majority of them show polysynthetic twinning. Irregular areas of chlorite occur in the ground-mass, but nothing is left to show what was the mineral that originally occupied these areas. A few small apatite prisms are present, and scattered through the whole rock are minute green flakes of chlorite. The rock is probably a syenite porphyry.

No rock except that above described is seen on the shores of this narrow bay north of the south line of sec. 27, T. 64–9. But where this line crosses the east shore of the bay there is a low ridge which shows angular fragments of fine grained greenish diabase similar to No. 489A. No rock is seen in place along the southwest shore of the promontory, on which are the corners of secs. 26, 27, 34 and 35, T. 64–9, but many angular fragments of the fine grained diabase occur at the water's edge. On the sharp point, at the southern end of this promontory, angular fragments of the diabase and of porphyry, similar to No. 490, are seen. Along the shore just east of this point are angular fragments of granite, and a little

further north this granite occurs *in situ*. Several outcrops of the same are seen along the shore before coming to the line between secs. 26 and 35, T. 64-9. At this place No. 491 was collected; this well represents the granite from the east shore of this promontory. It is a granite of medium grain, reddish color and compact texture; the feldspar varies from reddish to white, and the hornblende is in small grains and does not make up more than one-fifth of the whole rock. Quartz is present in small amount. Under the microscope this rock (No. 491) is seen to be a distinct hornblende granite. Quartz is present in larger quantity than is noticed in the hand specimen. The feldspar is more or less cloudy and many of the grains show a microcline structure and have a wavy extinction, as have also some of the quartz grains. The hornblende is quite fresh and of the ordinary green variety. A few scales of brown biotite are present, and also some green chlorite, which appears as an alteration product from the biotite. Bright brownish sphene is seen in considerable amount. Ilmenite, or magnetite, and apatite prisms are also present. This is the first true granite seen on this lake, but there is no reason to suppose that it is distinct from the syenite found elsewhere on the lake; in fact, everything seems to indicate that it is but an acid facies of the syenite. About 150 feet south of the above mentioned section line is a low outcrop of mica-schist, much twisted and bent. This schist is represented by No. 492, which is a fine grained compact mica-schist, and by No. 493, which is coarser and more properly gneiss. A few feet north of this the same schist is seen again; here it is cut by many granite dykes which vary from six inches to three feet in width. This granite is part of the same as that mentioned above (No. 491). The dykes in general run along between the cleavage planes of the schist, but some were seen cutting across these planes. The schist here is sometimes much changed near the contact with the granite, as is shown by Nos. 494 and 495, which are distinctly gneisses; the latter is decidedly reddish in color. There is no gradation from the schist or the gneissic parts of it into the granite; the contact between the two rocks is sharp and distinct, as is seen in No. 496. This specimen shows the two rocks, granite and schist, in contact; it was taken from the edge of a dyke one foot in width. The schist at this place is so twisted that no general strike can be made out. In places the granite includes pieces of the schist. A few yards north of this section line and back about 100 feet from the shore is quite a large exposure of the schists. These are bent some, but there is a decidedly general trend to the strike; it is N. 35° E., and the dip is almost vertical. Just beyond (north) this exposure of

schist, and in the strike of part of it, is another outcrop of the granite similar to No. 491. On one of these outcrops there is a small amount, one by three feet in area and one foot thick, of purple porphyry; the contact with the granite was sharp and a distinct line, and there was nothing to show whether this rock was part of a dyke or an inclusion in the granite. This porphyry is represented by No. 497; it has a fresh unaltered appearance and seems exactly similar to that already described under No. 490, except that that the latter is not very fresh. A short distance north of the section line (between secs. 26 and 35) and about an eighth of a mile from the shore is a small island composed entirely of granite (No. 498). This island is directly in the strike of the last mentioned outcrop of schist. The granite of the island (No. 498) is of rather fine grain and holds a considerable amount of quartz, but is the same granite as that described above (No. 491). On the northeastern end of this island the granite is jointed in a very noticeable manner; the joints split the rock into parallel beds that stand vertical and strike N. 70° E.

On the south shore of the little bay, in the S. E. $\frac{1}{4}$ of S. W. $\frac{1}{4}$ sec. 26, T. 61–9, the schist is seen in many places, and the granite is seen in contact with it at a few points. The schist here is well represented by the specimens collected near the south line of this section; and where the schist is in contact with the granite it takes on the same characters as seen in Nos. 494 and 495. In one place a small tongue of the granite was seen running across the strike of the schists, as shown in the accompanying illustration (Fig. 4). Along the shore of this bay the schist is twisted so much that no general direction of strike is noticeable.

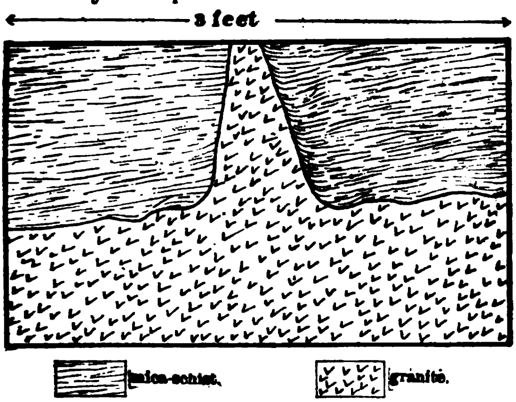


FIG. 4. Contact of granite and mica-schist; S. E. ¼ S. W. ¼ sec. 26, T. 61-9, west shore of Snowbank lake.

On the south side of this bay, near its western end and down at the water's edge, the schist is cut by a small dyke. This dyke is four feet wide, but was not exposed for over seven feet; the walls are parallel, stand vertical and strike N. 50° E. The line between the dyke and the schist is very sharp. The dyke rock is a purple

porphyritic rock similar to that already described under Nos. 490 and 497; it differs from these, however, in having distinct glistening biotite scales scattered through the ground-mass. The rock may be provisionally called a syenite porphyry. No. 500 is this rock from the centre of the dyke, and No. 501 is the same from one edge of the dyke. The schist at this place has a dip of 60° towards the east, and a strike almost due north and south. The schist from near the dyke is represented by No. 499; this is a rather fine grained gray biotitic gneiss. In section this gneiss (No. 499) is seen to be a holocrystalline aggregate of interlocking grains of quartz, feldspar, biotite and hornblende. Many of the grains are elongated somewhat in one direction, this is especially true of the biotite, and there seems to be a tendency for grains of the same size and of the same minerals to be collected somewhat in irregular parallel lines. This causes a decidedly schistose structure to pervade the rock. None of the mineral grains show any evidence of a clastic origin. The quartz is clear and limpid and is in larger grains than the other minerals; it makes up about half of the rock. The feldspar, while cloudy in small areas, is usually clear; most of it is orthoclase, but some good sized plagioclases are present. The biotite is brown and fresh; it, more than any of the other minerals, is chiefly confined to certain irregular lines. The biotite is in small scales, most all of which are arranged with their long axes in the direction of the schistosity of the rock. Hornblende of the ordinary green variety is present in a few irregular areas; it appears very fresh. All the minerals of the rock present a decidedly fresh and unaltered appearance.

The granite occurs at the west end of the little bay, in the S. E ¼ of S. W. ¼ sec. 26, T. 64-9, and also along the shore for a short distance north of this place. The point in the N. E. ¼ of S. W. ¼ of the same section consists of a high ridge of green schists. These shists are hard and of a general green color; they seem to consist of mica, chlorite and silicious matter very closely intermingled. The rock has a fine lamination due to rapid alterations in the arrangement of the constituents, thus producing laminæ of different hardness and composition; this lamination is very clearly shown on weathered surfaces; it is parallel to the schistose structure of the rock. In places the schist is conglomeritic, containing pebbles of all sizes, up to a foot in length, elongated in the direction of the strike. The strike is N. 20° E. and the dip is 75° to 80° towards the east. At the east edge of this ridge the schists are in contact with the granite. The contact line is sharp and runs parallel with the strike of the schists, but the granite sends off many small dykes

into the schists across the strike. No. 502 represents these green schists. No. 502A is part of one of the pebbles; it is a gray gneiss. No. 503 is the granite from one of the dykes four inches wide; this is a fine grained, reddish, hornblende granite.

The green schists extend from the point part way along the southeastern shore of the bay, in the N. W. ¼ of S. W. ¼ sec. 26, T. 64–9, but on this side of the bay, near its end, is a dark, compact, aphanitic rock holding white feldspar phenocrysts. This is probably a porphyrite (No. 504). It is massive at the shore, but on going back a few rods from the shore it becomes schistose, as is shown by No. 505. This porphyrite was traced eastward until it came within fifty feet of the green schists, but soil covered the contact. The porphyrite and the green schist at this place each had their distinct characters. The schistose structure of the porphyrite is parallel with that of the green schist. In one place the prophyrite is cut by a dyke of a fine grained syenite (No. 506). This dyke is four feet wide, stands vertical and runs east and west.

On the west side of this bay the green schists appear again and seem to get more massive on going northward, but the shore here was not carefully examined. In the S. W. ¼ of N. E. ¼ sec. 26 massive greenstone, into which the green schist seems to grade, is cut by a dyke of syenite porphyry, similar to No. 500. On the shore just north and east of this the greenstone and syenite are seen together. The greenstone here is quite massive in appearance and the contact with the syenite was seen in only one place; here it was a decidedly sharp line and two small pieces of the greenstone were seen in the syenite. At this place the syenite also cuts a gray diorite blotched with hornblende (No. 507); the relation of this diorite to the greenstone could not be determined. The syenite is itself cut by a fine grained greenstone (No. 508), in a dyke which varies from eight inches to two feet in width; this was traced for thirty feet. It may be that this is not a true dyke, but a part of the greenstone surrounded by syenite as it is decidedly similar to the greenstone and can not be distinguished from it in hand specimen. The syenite is here represented by No. 509, which is a reddish rock of rather medium grain. The greenstone is shown by No. 510.

Just north of this mica-schist is seen cut in every direction by dykes of the syenite, which vary in width from two inches to thirty feet. The mica-schist is shown by No. 511. Farther north there is a large mass of the schist exposed; here it varies from a mica-schist like No. 511, to a green schist (No. 512), which is very similar to the green schists described above. The strike here is N. 20°

E., and the dip is about vertical. These schists extend along the shore up to and beyond the line between secs. 23 and 26, T. 64–9. Sometimes they are cut by dykes of hornblende granite represented by No. 513. Near this section line the schists become very hard and compact; No. 514 from this place is a very siliceous, fine grained graywacke. Here the strike is N. 25° E., and the dip is about vertical. On a ragged bluff just north of this section line the schists are much crumpled and twisted and they become hard and very silicious. No. 515 fairly represents the schists at this place. The schists continue along the lake shore in secs. 23 and 24, T. 64–9. In places they are massive in appearance, but usually a lamination can be seen on their weathered surfaces; this, however, is much twisted in every direction, but there is a general northeasterly strike and a vertical dip. The schists in these two sections are well represented by Nos. 515, 516 and 517.

Where the line between ranges 8 and 9 crosses the north shore granite occurs, It is represented by No. 518, which is very similar to the granite and syenite found elsewhere on the lake. The granite here cuts the schists in dykes running in every direction. Some of these dykes are apparently a hundred feet wide, while others are not more than a foot. The contact between the two rocks is a very sharp line, as is shown by specimen No. 519, which was broken from the edge of a dyke eight feet wide. The schists at this place are represented by No. 520, taken within two feet of the granite; it is a fine, hard, silicious mica-schist. Here there is seen a small amount of a rather fine grained dark syenite (No. 521); this is distinct from the granite and is cut by it. The relation of this rock to the schists could not be determined. Just east of the range line the schists are seen in large amount. Here the strike is N. 70° E., and the dip southward from 70° to 80°. The schists, sometimes cut by the granite, extend along the shore to the bay in the S. W. ¼ of N. E. ¼ sec. 19, T. 64–8. On the west side of this bay the schists are graywacke schists. The strike is almost east and west and the dip varies from 65° to 80° towards the south. These schists are also seen at the north end and on the east side of this bay.

There is a small island in the N. E. ¼ of S. W. ¼ sec. 19, T. 64–8, on the eastern end of which is a large exposure of gray to reddish syenite of medium grain (No. 522). Mr. Wood went over most of this island and found it to be made of the same syenite.

Syenite from the shore in the N. W. ¼ of S. W. ¼ sec. 29, T. 64–8 is of medium grain and light gray color. Small areas of the feldspar have a peculiar yellow stain, No. 523.

Several outcrops on the east shore of the large island, which lies in secs. 30 and 31, T, 64–8, and secs. 25 and 36, T. 64–9, were examined. They are all composed of rather coarse syenite which holds large quantities of biotite. No. 524. Coarse syenite similar to this occurs on the east shore on the line between sec. 36, T. 64–8, and sec. 1, T. 63–9.

At the southwest end of the island that is crossed by the line between secs. 30 and 31, T. 64–8, there is an outcrop of fine grained biotite gneiss (No. 525).

Round lake.

This lake lies mostly in sec. 6. T. 63–8. The portage from Snowbank lake to Round lake is in the N. E. ¼ of sec. 1, T. 63–9. At the Snowbank lake end of this portage coarse syenite similar to No. 524 occurs. About half way over the portage a finer grained, reddish syenite (No. 526) is seen. But at the Round lake end of the portage is coarser syenite similar to No. 524. On the north side of the lake just west of the east line of sec. 1, T. 64–9, is a low outcrop of hardened mica-schist, cut by fine syenite veins. No. 527 shows the mica-schist and a small granite vein. The lamination of the schist is here twisted and bent, but there seems to be a general strike, No. 65° E.; however, this strike is not very pronounced. Further west on the shore are many angular fragments of syenite similar to No. 526. On the shore in the N. E. ¼ of S. E. ¼ sec. 1, T. 63–9, is an outcrop of the schist which is here more like gneiss (No. 528). In contact with this and separated from it by a sharp line is a small piece of syenite which held a small lenticular piece of the schist, or gneiss. Back from the shore is a small hill much covered by soil, but still exposing several angular fragments of rock that are undoubtedly *in situ* just below. Here a gneissic rock (No. 529) and red syenite (No. 530) were seen, and in one place they were in sharp contact; in other places they seem to grade into each other through No. 531 and 532; but nothing definite as to the relation of the syenite and gneiss could be seen here. Syenite again occurs on the shore a little south of this and is seen in angular blocks along the southwestern shore of the lake. On the shore in the N. E. ¼ of N. W. ¼ sec. 7, T. 63–8, is a low outcrop of a rather fine grained, brownish syenite (?) (No. 533). On the small stream that comes into the lake in this one-sixteenth section and about 100 yards from the shore is an exposure of coarse grained syenite. No other outcrops are seen along this stream until about a quarter of a mile south of the lake; here the ordinary coarse grained gabbro of the region occurs.

A low outcrop of mica-schist similar to No. 527 occurs on the north side of the lake in the N. W. ¼ of sec. 6, T. 63–8. A little further east syenite similar to No. 526 is seen. In the N. W. ¼ of N. E. ¼ of the same section the schists again appears. Here there is a decided strike of N. 70° E.; the dip is about vertical. The schists vary from mica-schist to graywacke-schist to quartz-schist. They are seen in several places along the northeast shore of the lake and also on the east shore. In some places the schists are cut by red syenite veins or dykes (No. 534). The most southern exposure of schists seen was on the east shore of the lake on the south line of sec. 6.

In the N. W. ¼ of N. E. ¼ sec. 7, T. 63–8, just south of the lake is a northerly facing gabbro bluff and at the base of it syenite is seen. The gabbro is the usual coarse grained gabbro common to this region. The position of the two rocks would indicate that the gabbro was the younger and overlay the syenite, but no positive proof of this was to be seen, as soil covers the junction of the two rocks. In the syenite a small dyke, ten inches wide, of a fine grained gabbro (?) occurs; this was exposed for only three feet in length. The contact with the syenite was a sharp line as is shown by No. 535. The dyke rock is represented by No. 536. The gabbro proper retained its coarse grained character as near to the syenite as it was exposed. No. 537 is the gabbro in the exposure nearest the syenite.

Disappointment lake.

This is also called Cheadle's lake. It is an irregular lake lying in secs. 3 and 4 of T. 63–8 and secs. 27, 28, 32, 33 and 34 of T. 64–8. Mica-schist occurs on the portage from Round lake. At the east end of the portage in the N. W. ¼ of S. W. ¼ sec. 3 is a low outcrop of schists, almost argillaceous in places. The strike here is N. 15° E., and the dip is vertical. The western shore of the lake has many large exposures of conglomeritic mica-schist cut in many places by fine red syenite. This syenite occurs in some amount on the portage to Snowbank lake (S. ½ of S. W. ¼ sec. 32) and is here seen cutting a peculiar gray rock. This gray rock (No. 539) seems to be a holocrystalline aggregate of gray feldspar grains among which are scattered hornblende prisms. In one place this gray feldspathic rock held many pieces of a darker rock, apparently a diorite; this is well shown by the specimen collected (No. 539). These pieces of diorite are of irregular shapes and all sizes up to those ten inches in diameter; none of them are lenticular in shape and they do not present the rounded outlines of pebbles. This gray rock lies

to the north of the portage and is between two ridges of mica-schist, but was not seen in contact with the schist. No. 539 is the fine red syenite which cuts the gray rock.

North of Disappointment lake

Two small lakes, one lying in the N. ½ of sec. 27 and the other in the S. E. ¼ of sec. 21, T. 64–8, were passed through. The rock on the shores of both of these small lakes was massive in appearance and varied from a very siliceous graywacke to a hard, fine grained green rock, resembling the ordinary greenstone of the region. Most of the shore line of the former of these lakes was examined, but no rock was seen excepting that just spoken of.

C. KEKEQUABIC LAKE AREA.

South of Kekequabic lake, in secs. 11 and 14, T. 64–7.

On the portage, in the N. E. ¼ of N. W. ¼ sec. 11, is a ridge of soft dark greenish rock, which is composed largely of biotite (No. 540). An irregular lake, lying in the centre of sec. 11, has been called River lake. Its shores are made of a fine grained gabbro-like rock. This varies from No. 541, a rather coarse facies from the west end of the lake, to No. 542, of finer grain from the portage in the N. E. ¼ of S. E. ¼ sec. 11. Most of the rock, however, is finer grained than No. 541. In places this rock has small veins or streaks running through it; these are composed mostly of biotite. At times they are quite close together, as shown by No. 543, and again very few of them are seen. No general direction for these black streaks could be seen. On the north side of the central west ern arm of this lake the gabbro-like rock held many angular and twisted fragments of a reddish syenite similar to that found on Kekequabic lake, and also of a fine grained greenstone (No. 544). These fragments are of all sizes up to those a foot in diameter; they are very irregular in outline, none of them are rounded, and they are often much twisted and stretched. No. 545 shows some of the fragments in the enclosing rock.

A few rods back from the shore, on the south side of River lake and near the entrance to the southern of the western arms of the lake, is a westerly facing bluff made up mostly of the fine gabbro-like rock. In the face of the bluff is a small area of syenite (No. 546). This is rather fine grained and is composed of pinkish feldspar, hornblende and some biotite. The syenite was seen within six feet of the other rock, but at this place neither of them showed any change from their normal condition.

On the east shore of the lake, near the centre, is a very micaceous facies of the gabbro-like rock (No. 547). Just south of this is a gray condition, probably of the same rock (No. 548); this weathers reddish.

The shores of Shoofly lake, which lies mostly in the S. E. ¼ of sec. 11 and the N. E. ¼ of sec. 14, are made of the ordinary gabbro of the region; this is rather finer, especially near the northern end of the lake, than the main mass of the gabbro. In one place, on the north side of the western arm of the lake, is a rock similar to that which makes most of the shores of River lake. South of Shoofly lake, and about in the centre of the N. ½ of sec. 14, is a large hill of white or grayish weathering gabbro.

Kekequabic lake.

On the south side of the little bay which extends into the N. E. ¼ of N. W. ¼ sec. 11, T. 64–7, is an outcrop of what has been called, in the former reports of this survey, chloritic syenite and chloritic gneiss. This rock has a considerable development on the shores of Kekequabic lake. Under the microscope it is seen to be a *pyroxene granite.* It is of a rather medium or fine grain and reddish color, and will be frequently referred to below. South of this outcrop and about 200 yards from the lake is an east and west running ridge made of a dark green biotite rock, similar to No. 540, which was taken from this ridge a short distance to the east. The pyroxene granite is again seen in low outcrop on the south side of the point, in the S. E. ¼ of S. W. ¼ sec. 2, T. 64–7. These two are the only exposures on the west side of the bay mentioned above. On the west side of this little point is a large outcrop of the pyroxene granite; it varies considerably within a few inches as to the amount of the pyroxene constituent. No. 549 shows the lightest colored and coarsest grained facies from this place. The rock presents an irregular layered appearance. These layers vary from an inch to ten inches in thickness, and even the same layer varies in thickness within a short distance. No difference in composition between the different layers could be made out, nor is there any arrangement, macroscopically visible, of the constituent minerals in such a manner as to cause splitting along certain lines. The rock did not show a tendency to split up into fine layers parallel to the larger ones. The rock has not yet been carefully studied in regard to the origin and significance of this structure. Fig. 5 represents the face of a small exposure of this granite and shows the regularity of the layers. The layers at this place dip from 10° to 15° towards the south.

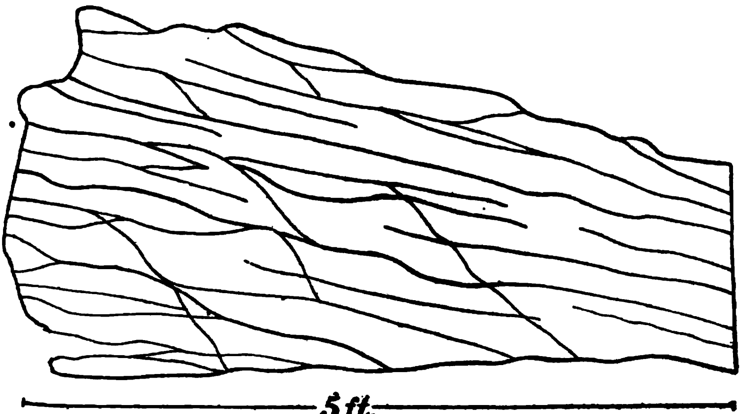


Fig. 5. Sketch showing the parallel layers into which the pyroxene granite is broken in the S. E. ¼ S. W. ¼ sec. 2, T. 64-7, south shore of Kekequabic lake.

No other outcrops are seen along the south shore in sec. 2 and the S. E. ¼ of sec. 3, T. 64–7. On going south from the lake for a quarter of a mile, on the line between secs 2 and 3, no rock is seen *in situ*, although the ground rises very rapidly from the lake shore. In the S. E. ¼ of S. W. ¼ sec. 3, on the shore, is a dark colored fine grained chloritic rock (No. 550), which extends westward and seems to become the angular weathering chlorite-biotite rock described in the 15th (1886) Annual Report, page 364.

The little promontory (not shown on the plat), in the S. W. ¼ of S. W. ¼ sec. 3, T. 64–7, is made of the pyroxene granite, which here contains distinct porphyritic reddish feldspars. The rock is well represented by No. 551. There is in the granite a division into layers similar to that described above, but coarser and less noticeable, which here dips northward 15° to 20°. At the base of this promontory is a low outcrop of a dark aphanitic rock (No. 552) which resembles some of the hardened argillyte slates of Knife lake. Just west of the promontory the chlorite-biotite rock is again seen, and this extends along the shore in sec. 4 and out to the end of the point in the S. W. ¼ of N. W. ¼ sec. 3, T. 64–7. On this point the pyroxene granite is seen in contact with this chlorite-biotite rock. A piece of the granite was seen, apparently surrounded by the other rock, but no positive evidence as to the relative age of the two could be seen, although the granite seems to be the older. The contact between the two rocks is a pretty well defined line. No. 553 shows the granite from this place; No. 554 the contact; and No. 555 the chlorite-biotite rock, which here holds a small amount of red feldspar, not seen in it elsewhere. On the north side of this point the granite occurs in a large exposure. It

is here finer grained than No. 553, and is represented by No. 556. It varies much, especially towards the west end of the exposure, and becomes darker colored and much finer grained, as is shown by No. 557. The chlorite-biotite rock is again seen at the extreme eastern edge of this point and in one place it is in contact with a small piece of the granite. On the north side of this point, near its base, is an uninterrupted exposure extending along the shore for thirty-five feet, and just east of it are other small exposures within a few feet of each other. Here there is a gradual change from a gray aphanitic rock much resembling some of the gray slate of this vicinity to the pyroxene granite, as represented by Nos. 556 and 557. The gray rock, however, shows no evidence of lamination or any definite slaty cleavage; it may be a very fine grained facies of the granite in which the porphyritic feldspars are lacking. As yet these specimens have not been studied microscopally. Nos. 601 to 615 represent this gradation; No. 601 is the gray rock; the specimens up to No. 612 were taken within distances of one to four feet going eastward from No. 601; Nos. 613, 614 and 615 occurred thirty to forty feet further east, and these pass into the facies of the granite represented by Nos. 556 and 557. From this point northward the rest of the west shore in sec. 4, T. 64–7, and the north shore in sec. 34, T. 65–7, were explored carefully for any trace of the pyroxene granite, but none was found.

The little island just northeast of the end of this point (S. W. ¼ N. W. ¼ sec. 3, T. 64–7,) has on its western end numerous angular fragments of dark aphanitic rock holding red feldspar crystals (No. 558). And on the south side of the island, and in some places on its west end, are also fragments of a dark conchoidally breaking argillyte (No. 559) very similar to No. 552 described above. These two rocks (Nos. 558 and 559) are undoubtedly in place just below the angular blocks. On the east end of the island is a small outcrop of a gray rock which has a fine grained granitic ground-mass holding very small porphyritic crystals of pyroxene and large ones of feldspar. This rock is numbered 560. It is the same rock as is found in considerable amount farther east on the shores and islands of this lake. This rock is found to be a very fine grained *pyroxene granite porphyry*, and will be spoken of in this report as such, or simply as *granite porphyry*. This rock was seen in sharp contact, in a loose block, with the black argillyte. Rocks Nos. 558 and 560 are probably different facies of the same rock; apparently intermediate stages were seen.

The island nearest the end of this point has a good sized bluff of granite near its centre; this is well represented by the specimens

described above, Nos. 556 and 557; it occupies the north half of the island. On the south shore is a dark rock with a green chloritic ground-mass in which are blotches of hornblende (No. 561); this seems to pass into a fine grained condition (No. 562) which is seen in sharp contact with the granite, but the relative ages of the two was not determined.

On the east shore of the little bay which lies at the southern side of the base of this point (S. W. ¼ N. W. ¼ sec. 3, T. 64–7,) is a slaty rock which, however, appears perfectly massive, except in weathered fragments where the slaty structure is brought out; no evidence of lamination was seen. At the northeast corner of this bay the slate is a black almost conchoidally breaking argillyte. Here on the weathered surfaces appears a fine lamination which strikes N. 20° E. and dips 75° toward the east. This rock is similar to No. 559, and it is peculiarly spotted by small gray to whitish blotches. Those spots are not very numerous, but are often quite distinct; they are of all sizes up to those five mm. in diameter. No. 563 shows this spotted slate. Going west along the north shore of this little bay the black slaty rock is seen in several low outcrops; it is cut by small veins which stand out above the surface of the rock on weathered surfaces. Near the west end of the bay, in the S. E. ¼ N. W. ¼ sec. 4, T. 64–7, is a soft green schist (No. 564), which strikes northeast and dips 70° toward the northwest. This rock shows no lamination, but has a very pronounced schistose structure. Just west of this, near the northwest corner of the bay, is the green chlorite-biotite rock.

The large island in the E. ½ of sec. 3, T. 64–7, and the three smaller islands that lie just west and northwest of it are composed of the pyroxene granite. The rock varies somewhat in grain and in the amount of the pyroxene constituent present. No. 565, from the east end of the smallest of the three smaller islands, shows about the normal condition of this granite. No. 566 is a coarser grained facies from the southern end of the largest and most northerly of the three smaller islands. On the north shore of the large island, near its western end the granite varies from a fine grained condition, like No. 565, to a dark, fine grained facies (No. 567). At this place was also seen a small band or inclusion of a gray and black slaty rock (No. 568) in the granite.

On the east shore of the bay in the N. E. ¼ of N. W. ¼ sec. 11, T. 64–7, is a fine grained green chloritic rock (No. 569). This is roughly schistose in places and at the water's edge is seen to be conglomeritic. The pebbles are rounded and do not appear distinct on fresh surfaces, but where the rock is waterworn they are

quite prominent. From this exposure a ridge runs eastward and a short distance from the shore the rock is distinctly laminated, as shown by No. 570. This exposure may have been a little displaced, but to all appearances it has not been. The dip is about vertical and the strike is N. 80° W. Just north of this and also in the S. W. ¼ of S. E. ¼ sec. 2, T. 64–7, are hills of fine grained pyroxene granite (No. 571). In the granite are a few dark inclusions of irregular outline; No. 572 is from one of these. The same fine grained pyroxene granite is seen in several places along the shore of the bay which lies in the E. ½ of S. W. ¼ sec. 2, T. 64–7, and the high hills just east of this bay are apparently composed of the same rock. These hills were visited in the E. ½ of S. W. ¼ of S. E. ¼ and N. E. ¼ of N. W. ¼ of S. E. ¼ sec. 2, and were found to be made of the same granite, well represented by No. 571. Syenite is also seen on the west side of the northward extension of this bay and on the point in the N. E. ¼ of S W. ¼ sec. 2. No other outcrops are seen northward along the shore in sec. 2, but on the point in the S. W. ¼ of S. E. ¼ sec. 35, T. 65–7 is a low exposure of a very fine grained facies of the granite (No. 576).

There is an island in the N. W. ¼ of N. W. ¼ sec. 2, T. 64–7, which is made up mostly of the pyroxene granite (No. 573); this varies somewhat in grain, but none was seen as fine as No. 571; it is noticeably porphyritic with reddish feldspars. On the west side of the island near the north end is a rock with a green aphanitic ground-mass in which are numerous glistening biotite scales,—No. 574. This rock is seen in contact with the granite; the contact line is sharp and distinct. The green rock is cut by many vein-like forms of a purple rock which is seen to be part of the granite, but they were not, actually, traced into the granite. No. 575 shows this rock in contact with the green rock. On a microscopic examination No. 575 is seen to be part of the granite. The two rocks were not apparently changed near the contact. Many angular and rounded fragments of the green rock are seen in the granite and a few fragments, or what appear to be such, of the latter, are seen in the green rock. The evidence of this exposure points to the more recent age of the granite.

About the foot of the shallow bay in the S. E. ¼ of S. E. ¼ sec. 35, T. 65–7, is an outcrop of a very light colored facies of the pyroxene granite porphyry (No. 577). Down at the water's edge this rock held a piece of a dark chloritic rock, similar to No. 574; this is probably an inclusion in the porphyry, but not enough was exposed to show this positively. A short distance east of this place a purplish condition of the granite porphyry is seen (No. 578). In

fragments from the side of this exposure there is a distinct arrangement of the porphyritic feldspar crystals in approximately parallel position. This could not be seen very well in the rock *in situ*, but at one favorable place this arrangement was in planes, or apparently so, running about east and west and dipping N. about 45°. That this direction is constant in this place is not clearly shown. The rock contains few pyroxene prisms, but a few were seen one-eighth to one-quarter of an inch in length. A short distance further east, in the S. W. ¼ of S. W. ¼ sec. 36, T. 65–7, is an outcrop of fine grained pyroxene granite, similar to No. 571.

On the main shore, just south of the west end of Stacy island (the island just off the shore and near the center of the N. ½ of S. W. ¼ sec. 36), a few feet from the water, is a low knoll of the granite porphyry well represented by No. 578, although here the porphyritic crystals are not quite as abundant as in that number. A few rods back from this knoll a high, precipitous hill rises, probably 200 feet above the lake; this hill extends along the lake shore in the S. ½ of sec. 36, T. 65–7. Mr. Wood went to the top of the hill, but found it to be all made of the same rock as is seen at its base,—a fine grained facies of the pyroxene granite (No. 579). This granite and the granite porphyry were traced within 150 feet of each other, but no nearer. Nothing was seen to indicate a gradation between the two rocks.

The granite porphyry occurs on the south shore of the lake in several places in the S. ½ of N. E. ¼ sec. 36, T. 65–7 and S. W. ¼ N. W. ¼ sec. 31, T. 65–6. Careful search was made for any general direction for the long axes of the feldspar crystals in this porphyry, but none could be found. In the S. W. ¼ of N. E. ¼ sec. 36, T. 65–7, just back from the shore, is a cliff about eighty feet high. The lower half of this is composed of the granite porphyry, and the upper half of a green conglomerate similar to that described half a mile southwest from this place on Stacy island.* The exact line of contact between the two rocks was seen in only one place, but the two were traced within two to five feet of each other for some distance along the face of the cliff. The contact line remains nearly horizontal for some distance and then suddenly runs upward. There seemed to be no blending of the two rocks at their junction, but the porphyry was roughly schistose and softer than usual, while the conglomerate seemed harder and more crystalline. No. 580 represents the porphyry and No. 581 the conglomerate at the contact; these two specimens were taken within two inches of each other. No. 582 shows the porphyry about four feet from the

* 15th (1886) Annual Report, pp. 150-151.

conglomerate. The dip of the conglomerate seemed to be toward the south, but nothing definite could be determined about this. The southwest side of Stacy island has quite an extensive exposure of the granite porphyry, but the junction of this and the conglomerate and the diabase on the island was not found. The porphyry here is rather coarser grained than usual and carries considerable biotite,—No. 583. The island just west of this shows many outcrops of the porphyry along its shores, in fact, this was the only rock seen on the island.

On the northwest end of the little point in the S. W. ¼ of N. W. ¼ sec. 31, T. 65–6 (south side of the lake) there is a dark, medium grained diabase. And on the northeast corner of this point is a low outcrop of a fine grained, gray, apparently holocrystalline rock; the ground-mass is grayish and in it are small, black needles, probably of hornblende, and a few scattered, rather irregularly outlined, feldspar individuals. There are also a few rounded pebbles, up to those two inches in diameter, scattered through the rock. The specimens collected (No. 593) show some of the pebble forms. Some of these pebbles are seen to be sub-angular, but most of them are rounded. They seem to be scattered irregularly through the rock and lie in no definite planes or layers; there is nothing in the rock to show any sedimentary lamination or bedding; it appears perfectly massive. This rock is seen in several outcrops in the N. E. ¼ of S. W. ¼ sec. 31, T. 65–6, and the shore is here usually lined with fragments of it. In the eastern part of this one-sixteenth section is quite an extensive exposure a short distance back from the shore. Here the pebbles, which have been steadily increasing in abundance eastward from the first mentioned outcrop, are very numerous. It would be almost impossibe to find any surface a foot square in the rock at this place which would not contain one or more pebbles, and many areas of this size would include as many as twenty. The rock is here represented by No. 594 and pebbles from it by 594A. This rock extends along the shore in a few outcrops nearly to the east line of sec. 31. The pebbles grow less abundant on going east from No. 594. No. 595 shows a more highly crystalline condition of this rock from the S. E. ¼ N. E. ¼ sec. 31. The noticeable features of this rock are its sharply outlined, rounded and sub-angular pebbles and the few scattering, white, apparently porphyritic, feldspar crystals, sometimes a quarter of an inch in length. No bedding, lamination or definite arrangement of the pebbles could be seen in the rock. It seems that this rock is a metorophosed conglomerate, and it strongly reminds one of certain facies of the Ogishke conglomer-

ate. In one place in the last mentioned one-sixteenth section there is a rough, parallel jointage in the rock; these joints dip southward about 25°.

In the eastern side of the above $\frac{1}{16}$ section is a low bluff of fine grained diabase and granite porphyry. The two rocks are seen in contact; the line between them is sharp and about vertical, but quite irregular, angles of each projecting into the other. There was nothing seen to determine the relative ages of the two rocks. No. 596 shows the granite porphyry about three feet from the contact; No. 597 is the same at the contact. No. 598 is the diabase at the contact, and No. 599 is the same six feet from the contact. No. 600 shows a coarser grained condition of the same also six feet from the contact. These last three grade into each other. It may possibly be that the specimens Nos. 598 and 599 are altered black slate, but this cannot be told macroscopically, and to all appearances they are continuous with and not to be separated from No. 600, which is a distinct diabase. The south shore of the lake, from this place to its extreme eastern end, was examined carefully for other outcrops of the granite porphyry, but none were found.

On the north shore of the lake, in the W. $\frac{1}{2}$ of N. E. $\frac{1}{4}$ of N. W. $\frac{1}{4}$ sec. 31, T. 65–6, there is an exposure of the granite porphyry which has above it, and on both sides of it at the water's edge, a green rock seemingly the same as the green schists found a short distance to the west. Here the green rock appears perfectly massive, except in a few places, where there is a very indistinct lamination, which is not sufficiently developed to enable one to determine the strike and dip. No. 616 is the porphyry thirty feet from the green rock; the porphyry holds a few small rounded areas of greenish material with rather indistinct outlines; one of these is shown in the specimen of the porphyry collected here (No. 616). The two rocks were traced within two feet of each other, but the exact contact was not seen. Nearest to the green rock the porphyry seemed to be finer grained (No. 617). No. 618 shows the green rock within thirty inches of No. 617, and the ill-defined reddish blotches which are seen in the green rock near the porphyry. No. 619 is the green rock about fifty feet from the porphyry. On the east side of this exposure the two rocks are seen close together. Here the porphyry held pieces of greenish material (No. 620) up to ten inches across; there was no very sharp line between these and the porphyry, but owing to the moss and lichen covered condition of the rock these green areas could not be well outlined. Search was here made for some general direction for the long axes of the feldspar crystals of the porphyry, but none could be found.

With the exception of a small area of fissile green schist on its western side, the point on which are the corners of secs. 29, 30, 31 and 32, T. 65–6, is made entirely of the granite porphyry. It here reaches its most typical development. This is the first exposure of the porphyry on the north side of the lake east of that described just above. Green slate is seen just north of this point, but between this and the porphyry there are no exposures; however, at the nearest point to these green slates the porphyry is finer grained than usual, as is shown by No. 621. A number of the largest pyroxene crystals were collected from the rock on this point, and also some of the feldspars, which showed dark centres. Very few inclusions were found here; probably not more than thirty were seen; these varied from half an inch to ten inches in diameter. They are mostly greenish in color and are not very sharply outlined, as is shown by No. 621A. No. 621B is from an irregularly but sharply outlined piece ten inches across. No. 621C is from an oblong piece, ten by five inches in area; around this piece there is distinct evidence of flowage, as is shown by the arrangement of the porphyritic feldspars.

Just south of the corner of the bay in the S. E. ¼ of S. W. ¼ sec. 36, T. 65–7, is a large ridge of pyroxene granite, spoken of before. (See No. 579 and accompanying description.) The eastern end of this ridge is made of a fine grained, flesh-colored rock (No. 622), a condition of the slates of the region, but no structural planes can be seen in it. This is in contact with the granite; the line between the two could not be clearly seen, but it seemed to run about vertical. No. 623 is the granite about thirty feet from the contact. No. 624 is the same at the contact, and No. 625 shows the slate at the contact. The last two specimens were taken within an inch of each other. This slate continues eastward and northeastward for about two hundred yards; it varies somewhat, as shown by Nos. 626 and 627. The relation between this rock and the dark, hard slates on the shore just north of this could not be determined.

In the N. E. ¼ of N. E. ¼ sec. 36, T. 65–7, where the granite porphyry overlies the greenstone,* two specimens of the former were collected. No. 628 is fine grained and was taken just at the contact of the two rocks; No. 629 is coarser grained, taken fifty feet from the contact. Careful search was made for some general direction of the long axes of the porphyritic feldspars, but their directions varied much; however, there were more places in which they ran about east and west than where they ran in other directions.

*This place has been described and figured in the 15th (1886) Annual Report, pp. 154, 367.

South from Kekequabic lake in sec. 31, T. 65–6, and secs. 6 and 7, T. 64–6.

A trip was made south from the lake through the S. E. ¼ of sec. 31, and through the E. ½ of sec. 6 to the little pond on the south line of this section east of the quarter post. From this pond I went through sec. 7 to the lake which lies in the S. ½ of this section and the N. ½ of sec. 18. The description will begin at Kekequabic lake and go southward over the high hill in the N. E. ¼ of sec. 6 to the lake just mentioned.

At the shore, in the S. W. ¼ N. E. ¼ sec. 31, the conglomerate, already described under Nos. 593, 594 and 595, is seen; this continues southward for at least an eighth of a mile. The pebbles become less numerous, but no less sharply outlined, on going away from the lake, and the rock becomes more coarsely crystalline and holds more of the apparently porphyritic white feldspars,—No. 630. No evidence of bedding was seen in this conglomerate. Beyond this and within fifty yards of the last exposure of conglomerate there are outcrops of slate. This slate varies from a dark almost black argillyte to one that is quite light gray. The lamination of the slate was twisted in some places, but as a rule this coincided with the slaty cleavage. The dip and strike were taken in many places before reaching the top of the large hill, whose summit lies in the N. E. ¼ of sec. 6; the dip was vertical and the strike varied from N. 35° E. to N. 55° E. The slate was intimately interbedded with a dark gray to greenish grit, but the lines between the two rocks were quite distinct. The bands of each varied from those a fourth of an inch across to those that were fifty feet or more in width. The grit held angular fragments of the slate and bands of the slate that were abruptly cut off; there were also places where bands of the slate were faulted and the grit existed between the faulted and broken ends of the slate bands. This grit makes up about half of the exposures to the hill top, but no exposure was composed entirely of this or of the slate alone. No. 631 is the black slate; No. 632 the grit, and No. 633 shows, as well as a hand specimen can, the intimate interbanding of the two. At the top of the high hill the grit is coarser grained than usual, as is shown by No. 634. The strike continues to be northeasterly until coming into the S. E. ¼ sec. 6, where it changes to N. 20° E., and a short distance farther south to direct north and south; the dip still remains vertical. This north and south strike continues to the pond which lies on the south line of section 6 east of the quarter post. No. 635 shows another condition of the grit resembling graywacke from just north of this pond. In this there is seen indistinct lam-

ination, but the other specimens of the rock do not show it; the rock (grit) elsewhere appears perfectly massive except for its interbanding with the slates. South of this pond the strike again swings round to northeast and the dip remains vertical.

About a quarter of a mile south of this pond is an outcrop of a porphyritic rock which is probably the same as the granite porphyry of Kekequabic lake. About seventy-five feet of this rock was exposed, the slates occurring both north and south of it within less than a hundred feet. The porphyry is numbered 636. The weathered surfaces of it show a rough schistose structure which runs N. 35° E. and stands vertical; however, this structure is not seen on freshly broken surfaces. The feldspar crystals are often arranged with their long axes parallel to the direction of the schistosity. The northeast strike of the slate and grit continues as far as they were seen,—*i. e.* almost to the lake which lies in the S. ½ of sec. 7 and the N. ½ of sec 18. We struck this lake about the centre of its north shore in the S. E. ¼ S. W. ¼ sec. 7. A short distance before reaching this lake the slate disappears and the grit, similar to Nos. 632 and 635, both of which facies here often show fine lamination on weathered surfaces, becomes in places conglomeritic and harder (No. 637). The pebbles are mostly rounded, some few are subangular, and they are chiefly of slate and a reddish granite porphyry, a pebble of which is shown in the specimen collected. This conglomerate shows no signs of lamination or schistosity. A short distance further south and almost at the lake shore is a more crystalline conglomerate holding pebbles of the same or similar reddish granite porphyry, and also of a fine grained red granite or syenite which resembles the pyroxene granite already mentioned so often. This conglomerate is shown by No. 638. In this rock, and also in No. 637, the pebbles varied from quite small ones up to those eight inches in diameter, but most of them were one to three inches across. In some places the pebbles were quite numerous and in others there were but a few to be seen. No definite arrangement of the pebbles in planes nor any elongation of them in one direction was seen.

The eastern half of the north shore of this lake (lying in the S. ½ of sec. 7 and N. ½ sec. 18) has some outcrops of the conglomerate represented by No. 638. On the east shore of this lake there are no outcrops until coming nearly to the south line of sec. 7. A short distance north of this line the ordinary gabbro of the region is seen. It is somewhat finer grained here than is usual, as is shown by No. 639. On going south along the shore a little farther the gabbro becomes coarser, similar to the usual coarse grained gabbro of the Mesabi range.

The object of this trip south from Kekequabic lake was to find how far south the conglomerate, described under Nos. 593, 594 and 596, extended, and to look for an eastern extension of the pyroxene granite which is seen in the E. ½ of sec. 2, T. 64–7. However, no granite nor any trace of it was seen. Numerous exposures of rock were seen, and there was probably no distance of a hundred yards where outcrops were wanting, until just before coming to the small lake mentioned above. And here there were not enough exposures to satisfactorily trace the conglomerate represented by No. 637 into that represented by No. 638. Still everything, except the more crystalline condition of No. 638, seems to point to their identity. The high hill passed over just south of Kekequabic lake seems to be at least 350 feet above the lake. This was thought to be the case on comparing it with Mallman's peak, which is 250 feet above the lake.*

Small lake in the S. E. ¼ of sec. 36, T. 65–7.

On the hill just north of the east end of this lake is a fine grained diabasic rock (No. 584). In places this is massive and again slaty. The strike of the slaty structure is N. 80° W., and the dip is towards the north 65° to 70°. Toward the base of this hill is a gray porphyritic rock with indistinct white feldspars in it (No. 585). This was seen in contact with the diabase rock and is found both above and below it, but the exact contact was seen in but one place where the two rocks were separated by a sharp line. Farther up on the hill the porphyry is represented by No. 586, which much resembles the pyroxene granite found a mile to the west. There were some apparently intermediate stages between Nos. 586 and 585, but no continuous exposures connected them. No. 587 represents another facies seen in contact with the slaty diabase (No. 584); this was apparently a stringer of the porphyry in the diabase. The same porphyry is again seen in a hill north of the centre of the lake and is in sharp contact with the slaty diabase. The latter is confined mostly to the upper part of the hill while the porphyry occurs near the water. No. 588 represents this porphyry from the north side of the lake.

At the northwest corner of the lake black argillytes are seen. They show no distinct bedding. On the west side of the lake near the north end is an exposure of the fine grained pyroxene granite (No. 589). And a short distance farther south is a hill whose base is made of the same granite, but of somewhat coarser grain (No. 590).

*The lake described above as having gabbro on its south shore is in the N. ½ of N. E. ¼, T. 64–7, and not in secs. 7 and 8, T. 64–6.

There is only one outcrop on the south side of the lake; this is a fine grained granite porphyry (No. 591) similar to that described from Kekequabic lake as pyroxene granite porphyry. I looked carefully for a definite arrangement of the feldspar crystals here, but none could be seen. Those, however, as seen in many places on Kekequabic lake, seemed to show evidence of a flowage in the rock before solidifying. On the east shore of the lake is a porphyry similar to No. 588. Here are a few irregularly shaped inclusions in the porphyry; No. 592 is from one of these. No rock intermediate between Nos. 588 and 591 was seen.

East of Kekequabic lake in secs. 28 and 29, T. 65–6.

A portage runs eastward from the most easterly point of Kekequabic lake to a small lake in the W. ½ of S. W. ¼ sec. 28. On this portage the hard black and gray argillytes, found just to the west, are also seen. The strike and dip were taken in one place; the former was N. 20° E. and the latter about vertical. On the east end of the portage is an aphanitic dark gray rock holding white feldspar crystals (No. 640); it also holds a few rounded pebble-like forms of rock similar to itself. On this portage and a short distance from the shore of the small lake this rock becomes softer and schistose and is not so distinctly porphyritic,—No. 641. It holds many rounded and subangular pebbles of fine grained granite, gray argillyte and a rock similar to No. 640. These pebbles present all the appearances of being water-worn and rounded; they are in places arranged in rough planes that run N. 25° E. and stand vertical. On the east side of the lake is an exposure of rock similar to No. 540, and on the same side nearer the north end is a large exposure of a peculiar gray granitic rock holding many small feldspars (No. 642). This is probably a metamorphosed grit. Back from the shore a little ways this rock becomes finer grained and darker in color, and is seen in sharp contact with a fine grained diabase (No. 643), which is probably in the form of a dyke. No. 644 shows this granitic rock at the contact, but this may be part of the rock similar to No. 641. North of this and extending to the portage is rock similar to No. 641; it is decidedly conglomeritic. I noticed a few scattered greenish inclusions or pebbles in No. 542.

From this lake is a portage running north for about fifty yards to another small lake. According to the plat this ought to be Zeta lake, but very probably the bay that is represented at the southwest corner of Zeta lake is separate from that lake. On the portage from this small lake to Zeta lake the argillaceous slates again occur; they here strike N. 20° E. and dip 80° to 85° towards S. 20° E.

D. SAGANAGA LAKE AREA.

The work on this area was confined mostly to its southwestern and western borders. The limits of the granite were traced pretty accurately from the east side of sec. 15, T. 65–5, west and northwest to the E. ½ of sec. 24, T. 66–6, where the western line of the granite crosses the international boundary.

West Sea Gull lake.

The southwest corner of the point that is crossed by the south line of sec. 8, T. 65–5, is composed of a coarse grained gray granite (No. 645). Just east of this the rock is much decayed and very schistose, as shown by No. 646. This is undoubtedly only a decayed portion of the granite, and the two are not separated by any line. East of this the granite, like No. 645, is again seen, and it also outcrops on the north side of a little island just south of this point. There are no outcrops at the end of the little bay in the N. W. ¼ of N. E. ¼ sec. 17, but a short distance to the east are rounded knolls of granite. Here the rock is darker colored and carries less quartz than most of the granite on the lake; this facies is shown by No. 647. On the south shore of this bay and near its eastern end is a low outcrop of the ordinary granite, and a short distance to the west are large, bare, rounded domes of a dark green slaty rock which appears massive in places. At the water's edge the granite was seen in contact with the slaty rock, and it also held angular fragments of the same. The granite at the contact was coarse grained and similar to No. 645. The green slaty rock is represented by No. 648. The rounded domes of the green slate are cut by numerous branching veins or dykes of granite, which is coarse grained and similar to No. 645; it is shown by No. 649. These veins are of all sizes up to those twenty feet in width; the sides of them are not finer grained than the centres. A second set of granite veins, few in number, also cut the green rock and the coarse granite veins; this second series is composed of a fine grained reddish granite (No. 650), and these veins are of finer grain near their edges than at the centre. This same rock was seen cutting the ordinary granite on the north side of the bay. On the west shore of the bay in the N. E. ¼ of N. W. ¼ sec. 17, is a massive aphanitic greenstone (No. 651). On going north along this shore this rock seems to pass into a massive diabasic rock, which comes in contact with the granite, which holds pieces of the diabase and sends stringers into it. No. 652 is the diabase from the granite contact. Granite occurs in a few outcrops along the shore in the

N. W. $\frac{1}{4}$ of the last mentioned $\frac{1}{16}$ section, but before coming to the north line of sec. 17 the aphanitic greenstone again appears. This is seen where this section line cuts the shore, and also in several places in the S. W. $\frac{1}{4}$ of S. W $\frac{1}{4}$ sec. 8, T. 65–5. It varies from a rock like No. 651 to one that is harder and gray to greenish in color and resembles a very compact and fine grained graywacke (No. 653). Granite is again seen on the blunt point which is touched by the west line of sec. 8 south of the quarter post.

On the shore in the N. W. $\frac{1}{4}$ N. W. $\frac{1}{4}$ S. W. $\frac{1}{4}$ sec. 8, T. 65–5, and also at the west side of the same $\frac{1}{64}$ section, where the west line of the section crosses the shore, are outcrops of conglomerate. The matrix of the conglomerate is gray to greenish in color, quite coarse and full of quartz grains. In this matrix are many pebbles, among which red jaspilyte is conspicuous. No. 654 shows this conglomerate. It is part of the Ogishke conglomerate which is seen in so extensive development to the southwest on Ogishke Muncie lake. There is nothing at this place to definitely show the dip and strike. This conglomerate rises in a ridge just west of the shore, and in places the matrix is entirely free from pebbles and quite schistose. This schistose structure runs N. 35° E. and stands vertical. A short distance further west, but separated from the conglomerate by low ground where there are no exposures, is a ridge of granite running northeast and southwest. This granite does not differ materially from that found at the lake shore; it is represented by No. 655. This granite ridge is about 100 feet wide; beyond it the conglomerate again appears and extends westward for at least a quarter of a mile from the lake. Beyond this is low ground with no exposures. On this last ridge the granite and conglomerate are seen in contact. The granite runs in bands in the conglomerate, thus giving the appearance of "interbedded" granite and conglomerate. These bands of granite vary from one to thirty feet in width, and about a dozen of them were seen. The contact lines between the granite and conglomerate are distinct, but rather irregular; however, they do not run across the strike of the conglomerate for more than six inches at a time. In some places it is rather difficult to tell which rock is under foot, but when the two rocks are seen together they are easily distinguished. The granite does not vary in grain, especially at the contact, but is of a uniformly coarse grain. No. 656 shows the conglomerate at the contact, and No. 657 is the granite from the same place. No. 657A is the granite four feet from the contact. No. 658 shows a more crystalline condition of the conglomerate matrix. Interbedded with the conglomerate is a small amount of argillaceous slate. The matrix varies from that

shown by No. 654 to a fine grained green facies shown by No. 659. Bands of the matrix free from pebbles are common, and in such cases the rock is occasionally laminated. The strike at a place 100 yards east of the granite bands is N. 10° E., but near these bands it varies from N. 10° W. to exact N. and S.; the dip in all cases is vertical.

The granite is again seen on the northeastern side of the round point in the S. W. ¼ of S. W. ¼ of N. W. ¼ sec. 8, and also on the point just east of this. At the southwest corner of the bay, which runs into the S. E. ¼ of N. E. ¼ sec. 7, is a green rock similar to No. 651; it is cut by the granite and is also seen in sharp contact with a fine grained purplish porphyritic rock, which seems to be in the form of a dyke, although this could not be definitely seen. This porphyritic rock is the same as Nos. 660 and 661. On the northwest shore of this bay is a ridge of granite. Granite is also seen in several places on the north shore of the bay, and in one place is in contact with a purplish rock, which is much decayed and resembles a porphyrite. The line between this rock and the granite is very distinct, and the former seems to cut the latter in the form of a dyke. The granite is unchanged at the contact, but the other rock here seems to be finer grained than usual. No. 660 shows this porphyrite (?) from the contact, and No. 661 is the same twenty feet from the granite.

Along the west shore of the lake the granite is seen in several outcrops in the N. E. ¼ of N. W. ¼ sec. 8 and S. W. ¼ sec. 5. Near the end of the point in the N. E. ¼ S. W. ¼ sec. 8 is a diabase dyke in the granite. This dyke is also seen in the bay on the west of this point. No. 662 represents the diabase of this dyke; it is finer grained near the edge. The same dyke is also seen on the west and east sides of the end of the point in the N. ½ of S. E. ¼ sec. 5. It has an east and west direction and varies from thirty to forty feet in width. On going west from the southwest side of the bay in the N. W. ¼ S. W. ¼ sec. 5 the same dyke is again seen in contact with the granite, and both rocks form a ridge that runs west from the lake for an eighth of a mile. Beyond this (west) is a swamp with no exposures, and then not less than a quarter of a mile from the lake is a ridge running northeast and southwest. This ridge is made of a fine grained laminated slate (No. 665), which varies from a gray to a green argillyte. The lamination and slaty structure coincide and strike N. 15° E. and stand vertical. South of this ridge a few rods is another composed of a green to gray grit (No. 664), which is like the matrix of the conglomerate

above described—Nos. 654 and 659. No pebbles are visible in this rock, nor is there any lamination, but in it are a few narrow bands of slate similar to No. 663. These stand vertical and strike N. 30° E.

The granite is seen in several outcrops on the shores of the bay in the centre of the N. ½ sec. 5, and also on the point on the east side of this bay. The east shore of the point in the S. E. ¼ S. E. ¼ sec. 8 was also examined and found to be composed of granite.

The granite of West Sea Gull lake varies considerably in grain and also in the amount of chlorite or hornblende present. The fresh rock is a hornblende granite, but in many places this has been completely changed to chlorite. There seem to be two feldspars present,—a yellow and a pink one. No. 675 is as fresh as any of the granite of this lake and may be taken as a typical example of it. This specimen was taken from the east side of an island in the S. W. ¼ S. E. ¼ sec. 8.

Small lake in the N. W. ¼ of N. W. ¼ of sec. 8, T. 65–5.

This lake is not shown on the government plat. On the east and north shores of the lake no rock exposures were seen. On the west shore near the north end is a ridge composed of the Ogishke conglomerate similar in every respect to that described from West Sea Gull lake in this same section. The conglomerate was traced west over the ridge for a short distance; the pebbles became fewer in number and the rock in places was slaty, almost exactly like No. 663. At one place the slaty rock was crumpled as if it had been pressed in a direction parallel to the strike; this was seen for only a short distance. In places the matrix showed a lamination and again it was broken into long flags. The lamination, the long direction of the flags and the banding and slaty cleavage of the slaty areas were all parallel and stood vertical; the dip was N. 15° E.

On the west side of the lake near the south end the granite is seen at the shore. It is chloritic and holds large quartz grains and reddish feldspars,—No. 665. The conglomerate is seen not more than an eighth of a mile west of the shore, but the junction of it and the granite was not found. What is said about the conglomerate in the last paragraph will apply equally well here, except that the strike is N. 20° E. Back from the shore the granite becomes schistose in places; this schistose structure stands vertical and strikes N. 20° E. Here the rock is similar to No. 665, excepting for this schistosity. A little further west the granite has changed to a yellow rock holding large quartz grains,—No. 666.

This and the conglomerate were separated by several yards of soil where there was but one exposure. This exposure is within twenty feet of the conglomerate; the rock is shown by No. 667, which appears to be a more decayed part of the granite. On the west side of this exposure there seems to be, although this could not be distinctly made out, an interbanding of rock similar to No. 667 and a rock similar to this, but finer grained and greener. It is, however, possible that this last is but a less weathered condition of the former, and that they are both decayed conditions of the granite. The two rocks (if there are two) are shown by No. 668. Twenty feet west of this is the conglomerate with the matrix like No. 664.

No other rock exposures occur on this lake, but between its southeast corner and West Sea Gull lake is a knoll of the ordinary granite.

Small lake in the S. ½ of N. W. ¼ of sec. 16, T. 65-5.

From the foot of the bay of West Sea Gull lake, in which are the corners of secs. 8, 9, 16 and 17, a portage leads south to this small lake. The ordinary granite is seen in two or three places on and near this portage trail. Granite also occurs where the west line of sec. 16 cuts the north shore of the little bay that projects into the S. E. ¼ N. E. ¼ sec. 17, and also a short distance on either side of this line. On the west side of this little bay is a rounded hill, the northern part of which is composed of granite and the southern part of a hardened mica-schist (No. 669), which in places looks almost like a fine diabase. The granite is in sharp contact with this rock and cuts it with many vein-like forms. These veins are like the granite elsewhere and differ only in being finer grained in places. The whole exposure much resembles that seen in the N. W. ¼ N. E. ¼ sec. 17, West Sea Gull lake, and described under Nos. 647 to 650.

Back from the shore at the southwest corner of this little bay the same hardened mica-schist is seen, and it occurs again within a few feet of where the west line of sec. 16 cuts the south shore of this bay. Continuing along the southwestern shore of the lake more of the hardened mica-schist is seen; it varies to a green slaty rock and also to a green siliceous schist (No. 670). These were all cut by granite veins. On the south shore near the east end of the lake the granite is seen in a large outcrop. No outcrops were seen on the north shore of this lake excepting on the little point in the centre of the N. ½ S. W. ¼ N. W. ¼ sec. 16, and on the small island just off this point; here the rock was granite.

A small stream flows from this lake east to Sea Gull lake, in the S. E. ¼ N. W. ¼ sec. 16, and just south of the stream is a short portage between the two lakes. Granite occurs a few feet south of this portage.

Sea Gull lake.

The western shore of this lake, in sec. 16, T. 65–5, was rather carefully examined. There were many exposures, but these were all granite except on the south side of the bay in the N. E. ¼ S. E. ¼ sec. 16, and on the shore in the S. E. ¼ S. E. ¼ sec. 16. Here were outcrops of the same hardened mica-schist, varying to a green slaty rock, as described above. (Compare Nos. 669 and 670.)

Where the east line of sec. 16 cuts the south shore the granite is seen; here it is chloritic, rather decayed and somewhat schistose,—No. 671. Back from the shore a few rods and just west of the section line is a ridge of fine grained mica-schist, varying to chloritic schist. Farther south and on the north side of the east and west ridge, on which is the southeastern corner of sec. 16, is a small amount of fine grained granite (No. 672), probably a stringer from the main granite mass. The south side of this ridge is made up of a greenish mica-schist (No. 673); here the strike of the schistose structure is N. 70° W. and the dip is vertical. A short distance further south is another ridge of the same rock. No lamination was seen in this schist; it varies from a fine mica-schist, like No. 673, to rock similar to Nos. 651 and 670. On this last ridge is a small amount of a gray quartz porphyry in the schists; this appeared like a band running parallel with the schists;—No. 674.

Red Rock lake.

The outcrops on the west end of the bay that projects into the N. E. ¼ N. E. ¼ sec. 5, T. 65–5, are all granite. The bay which lies in the E. ½ N. E. ¼ sec. 32 and W. ½ N. W. ¼ sec. 33, T. 66-5, was examined. Here there are several outcrops of the ordinary granite.

On going north from West Sea Gull lake the granite becomes coarser in grain and more pink in color; it is hornblendic rather than chloritic. The quartz grains are especially large,—commonly a quarter of an inch across and sometimes as much as half an inch. Frequently one-third of the rock is made up of these large quartz grains.

Saganaga lake.

The coarse grained granite of Red Rock lake is found also on Saganaga lake. No. 686 from the point in the S. W. ¼ N. E. ¼ sec. [illegible], T. 66–5, fairly represents the granite of the main part of Sag-

anaga lake. It is of decidedly coarse grain and of a pinkish color. The large irregular areas of quartz are very noticeable. The feldspar is pinkish and sometimes yellowish. Hornblende is present in considerable amount and is more or less changed to chlorite.

On the east end of a long island which lies just south of the point in the S. W. ¼ N. E. ¼ sec. 22, T. 66–5, is a a diabase dyke in the granite. This dyke is ten feet in width and has a north and south direction.

The island which lies mostly in the S. E. ¼ N. W. ¼ sec. 14, T. 66–5, is composed of a rock which varies from a fine grained syenite, made up almost completely of feldspar and very little hornblende, to a very coarse grained syenite of the same kind, and again to a rock composed mostly of feldspar and quartz, the latter in very large grains. In places it is porphyritic and has a reddish feldspathic ground-mass, in which are red feldspar crystals and sometimes quartz crystals. Disseminated through the rock in veins, and also in small grains, is a dark violet fluor spar. There are also some few small yellow grains in the rock which resemble talc. At the north side of this island is a large mass of white quartz which extends along the shore for over a hundred feet. This quartz mass was not seen in other places on the island. Mixed in with the quartz are fluor spar, yellow talc and red feldspar; the latter often shows cleavage faces eight or ten inches across. Small quartz crystals are seen in cavities; these crystals vary from colorless ones to those that are purple and even black. The rock from this island is represented by Nos. 676, 677 and 678.

In the N. E. ¼ N. W. ¼ sec. 14, T. 66–5, south side of the large island crossed by the north line of this section, the rock appears to be porphyritic with large quartzes; this is probably a decayed condition of the ordinary granite, the quartz being the only mineral unaltered. This rock is represented by Nos. 679 and 680. This rock is seen further east in the same $\frac{1}{16}$ section along the shore of the island. In the S. W. ¼ S. E. ¼ sec. 11, the ordinary granite occurs, and this is also seen in several places in the S. ½ of sec. 11, on the west shore of this large island.

All the outcrops seen along the shore in secs. 10 and 9, T. 66-5, were of the usual coarse grained granite. On the little island in the extreme southeast corner of sec. 8 the granite is seen in contact with a fine grained reddish aplite, which seems to be in the form of a dyke. The granite did not appear to be changed at the contact, but the other rock was finer grained. No. 682 shows this aplite ten feet from the contact, and No. 681 is the same from the contact. The shore was followed pretty closely in secs. 17, 18 and

19, T. 66–5, and many exposures were seen. No. 683, from the small island in the mouth of the bay which projects into the N. E. ¼ N. E. ¼ sec. 19, well represents the rock in sec. 17 and the S. E. ¼ of sec. 18. On the west side of the point in the extreme south-eastern corner of N. E. ¼ S. E. ¼ sec. 18, the rock is decayed and the feldspar no longer shows distinct cleavage faces,—No. 684. Along the points in the S. W. ¼ S. E. ¼ sec. 18, the rock is much decayed and broken, but it still seems to be part of the granite,—No. 685. Just north of this, on the Canadian side and not more than two hundred feet distant, the ordinary granite similar to No. 683 is seen.

Outcrops of granite, similar to No. 683, continue along the east, south and west shores of the bay, which lies in the W. ½ of sec. 19, T. 66–5, almost to the west line of this section. At this line the rock is decayed, as shown by No. 687. On the Canadian side, just north of this, apparently the same rock is seen in a very schistose condition; it is also broken into well defined flagstones from one to four inches in thickness. These flagstones stand parallel to the schistosity, which strikes N. 40° W. and dips 70° towards the southwest. Similar rock, but with less schistose structure, is seen on the Minnesota side near this section line. The specimens collected from the Canadian side, Nos. 688 and 689, are not as full of large quartz grains as most of the rock here, but they are the soundest pieces that could be obtained. No. 689 is but a weathered condition of No. 688, as is shown by one of the specimens marked 689. It is not absolutely certain that this rock is part of the granite, but all indications seem to point that way. It is seen in many places in this vicinity and will be spoken of as altered granite.

Along the east shore of the bay in the S. E. ¼ sec. 24, T. 66–6, the rock is similar to Nos. 688 and 689, although sometimes of coarser grain. The rock along this shore in the E. ½ N. E. ¼ of the same quarter section is well represented by the last two numbers, by No. 690 and by Nos. 693 and 694, to be described below. In this subdivision of sec. 24 the altered granite is seen in contact with slates. There is, however, only a small mass of the slate in contact with this altered granite, but large amounts of it appear just to the south of this place. The contact is sharp and well defined. No. 691 shows the slate, which is a gray to a black argillyte No. 692 is the altered granite at the contact. These two specimens were taken within three inches of each other. The lamination and slaty cleavage of the slates are practically parallel, although the specimens collected (No. 691) do not show it. The strike is N. 34° W., and the dip is 68° towards S. 56° W. Rock No. 692 passes

gradually into Nos. 693 and 694, and these three numbers were taken within a distance of four feet. No. 695 is from the slates about a foot from the contact; it is probably an interbedded band of graywacke. A small bed of slate, six inches wide, is seen with the altered granite on each side of it; this slate (No. 696) is very fissile and of a drab color, appearing considerably different from the ordinary slate (No. 691). The contact between the two rocks in both places is parallel to the strike of the slate, and the altered granite at the contact is finer grained, like Nos. 692 and 693, but grades off rapidly into a coarser grained facies, like No. 694. There seems to be no line between the ordinary granite (No. 683) and the rocks numbered 688, 689, 690, 692, 693 and 694, but there is a very evident line between the slates and these rocks. This altered granite is light gray or greenish gray in color when not weathered, but on weathering becomes brownish and seemingly coarser grained. This weathering in places does not extend more than a quarter of an inch into the rock, and in other places it goes as far as three inches from the surface; (compare specimens Nos. 688 and 689.)

On the east shore of the bay in the S. E. ¼ sec. 24, T. 66–6, just north of the little stream which flows from the lake to the south, the altered granite and slate are again seen in contact. Here there are three bands, three to six feet wide, of the altered granite, or what appears to be such, in the slate; the rock of these bands is shown by No. 727. This rock is sharply separated from the slates; in places it becomes coarse by the addition of large quartz grains. Just away from the contact are bands of grit in the slates like Nos. 729 and 730. Near the contact the slates hold bands, from one-half to six inches wide, of a fine grained graywacke (No. 728). It is hard to distinguish in some cases between the grit and the altered granite near the contact between this latter rock and the slates; almost the only difference to be seen is in the peculiar weathering, mentioned above, of the altered granite, but when this rock is in large masses it can be easily distinguished. The strike of the slates at this place varies from N. 90° W. to N. 20° W., and the dip from 70° to 80° towards the south. The lamination and slaty cleavage are parallel, but the rock has been much twisted. In some of the slaty beds there is a distinct schistose structure, which is different in direction from the slaty cleavage; this schistosity strikes from north and south to N. 5° E., and dips 70° to 80° towards the east. South of this little stream the dip and strike are rather constant; the latter is 75° towards S. 60° W., and the strike N. 30° W. Here was seen a bed of the grit, shown by No. 729, which held twisted fragments of

slate. A little further south was another bed of the same, which had one side a very irregular line and one end was abruptly cut off by the slate. The grit from this place is shown by No. 730. The east shore of this bay was carefully examined south of the above mentioned stream. Many places were found where the grit held angular and twisted fragments of the slate. These fragments were in most cases entirely disconnected from the slaty bands and completely enclosed in the other rock. Nos. 731 and 732 are samples of the rock which held the slate fragments. In other places rock like this gradually passed into the slate. These bands of slates and grit continue along the south and west shore of this bay nearly to its north end, where the altered granite is again seen, at first holding beds of the slate. The phenomena here seem to be the same as described above. The strike of the slates was taken in several places; it averages N. 30° W., and the dip was 70° to 80° towards the southwest. However, there were some local variations in the strike; these varied from N. 20° W. to N. 45° W.

On the west shore of the bay in the W. ½ of sec. 19, T. 66–5, near the west line of this section, a series of specimens was collected representing the change from the granite to the so-called altered granite. These specimens were taken within a distance of fifteen feet; they are numbered from 717 to 725 inclusive. No. 720 seems to be only a decayed condition of No. 721. The exact order of the specimens to show the steps of this gradation is not certain, as the rock exposed was much broken into angular fragments, some of which were displaced a few inches. At this place the granite held one inclusion of a fine grained greenstone (No. 726).

At the portage from Saganaga west to Oak lake the altered granite is again seen, and also just west of this on the south shore of Oak lake. Here it holds small grains of white feldspar, No. 733. Farther west on the south shore the slates are seen holding bands of what appear to be the altered granite,—No. 734. Here the strike is N. 35° W., and the dip about 80° towards the southwest. The slate formation becomes well established before reaching the west end of Oak lake.

Wind lake and vicinity.

This lake lies in the E. ½ E. ½ sec. 25, T. 66–6, and the W. ½ W. ½ sec. 30, T. 66–5, with a small bay projecting into the S. W. ¼ S. W. ¼ sec. 19, T. 66–5. It is connected with Saganaga lake by a small stream which flows from the north end of this small bay into the bay of Saganaga lake, which lies in the S. E. ¼ of sec. 24, T. 66–6.

On the west side of Wind lake, in the S. E. ¼ N. E. ¼ sec. 25, the rock is composed of intergrading and interbedded bands of a greenish slate (No. 697), a graywacke (No. 698) and a grit (No. 699). The banding and slaty cleavage coincide in direction. The strike is almost exactly north and south, and the dip is 75° to 82° towards the west. Back from the shore a hundred yards is a bluff composed mostly of graywacke and grit; here the general strike is north and south, although there is much local twisting. On the surface of the rock the glacial striæ are very distinct and run very nearly south. A short distance further south on the west shore, in the N. E. ¼ S. E. ¼ sec. 25, the rock at the shore appears almost massive and is broken up into angular blocks. There are many narrow bands, one to four inches wide, of slate in the rock, which strike N. 15° W. and dip W. 82°. The slate is laminated in places and is almost exactly similar to No. 691. The main mass of the rock varies from a graywacke, like No. 698, to a grit, like No. 699, and is very hard and compact. Frequently the slaty bands grade into the other rock. This exposure is at the north entrance to the little bay in the same $\frac{1}{16}$ section. At the west end and at the south entrance to this bay are exposures of the same rock, but with fewer slaty bands. The strike is rather imperfectly shown, but seems to be N. 20° W. No. 700 is the graywacke from the west side of this bay; it somewhat resembles some facies of the altered granite found in contact with the slate on Saganaga lake. South of this bay no exposures are seen on the west shore, and there are none on the south shore. On the east shore near the south end of the lake, and back a few yards from the water, is a large exposure of the graywacke, in which the lamination is indistinct. On the southwest side of this exposure of graywacke is an area of black to gray slate about eight feet wide and twenty-five feet long, and exposed for six to seven feet in hight. The slaty cleavage is distinct, striking N. 50° W. and dipping 85° S.W. The lamination is extremely distinct; it has the same strike but dips 52° towards the northeast. This lamination fades out gradually into the graywacke. The slate is to all appearances the same as that seen on the west side of the lake. No. 701 shows in a small way this discordance of slaty cleavage and lamination. This exposure is in the S. E. ¼ S. W. ¼ S. W. ¼ sec. 30, T. 66–5.

Several outcrops of rock varying from slate to graywacke occur on the east shore in S. W. ¼ sec. 30. The slaty cleavage and the lamination, where seen, always coincide. The strike on the little point in the W. ½ N. W. ¼ S. W. ¼ sec. 30 is N. 5° W. and the dip is 70° W. The little island just off the point in the S. W. ¼ N.

W. $\frac{1}{2}$ sec. 30 has a fine exposure. Here the bedding of the graywacke is seen to good advantage; strike N. 22° W. and dip 70° towards S. 68° W. On the point at the west entrance to the bay in E. $\frac{1}{2}$ S. W. $\frac{1}{4}$ N. W. $\frac{1}{4}$ sec. 30 the strike is N. 22° W. and the dip 70° to 76° towards S. 68° W. The shores of this bay are low and show no outcrops, but on the shore about 300 feet east of the last named point is an outcrop of altered granite like No. 689. It is roughly schistose; this structure is vertical and runs north and south. Less than fifty yards east of this is a ridge of the same rock very coarse grained. A little further north (in the E. $\frac{1}{2}$ N. W. $\frac{1}{4}$ sec. 30) the rock at the shore is the same as in the ridge. In places four-fifths of the rock is composed of quartz as is shown by No. 702. Apparently in this altered granite was a small, illy exposed area of brownish fissile slate. No. 703 shows this slate and No. 704 a condition of it near the ordinary altered granite. It appears as if this slate is part of the slate formation of the region enclosed in the other rock, but nothing definite could be made out concerning it.

The altered granite extends along the east shore in the N. W. $\frac{1}{4}$ sec. 30, and to the extreme northern point of the lake. Here, on the east side of the stream which flows into Saganaga lake, the rock is altered granite, but on the west side of this stream the slate and graywacke formation appears. The slates hold bands of what seem to be the altered granite, and also of graywacke and grit. It is here impossible to distinguish between these rocks, in fact it seems as if the so-called altered granite was a part of the grit and graywacke. Nos. 705, 706 and 707, from the east end of this exposure, show facies of the altered granite or of the grit and graywacke. No. 708 certainly seems to be grit; it was taken over fifty yards from the main mass of the altered granite. In one place one of these questionable bands was seen to hold fragments of slate near its edge,—No. 709. In no place did I see any of the so-called altered granite bands cutting across the strike of the slates. Nearest the main mass of altered granite the slates are brownish, as those found inclosed in the other rock (see Nos. 704 and 705) and are shown by No. 710.

The slaty formation extends along the north and west shores of of Wind lake. Northwest from the northwest corner of the lake is a high bluff composed mostly of grit and graywacke, the former apparently somewhat re-crystallized (No. 711). Here the dip is 75° to 80° towards S. 60° W. About a quarter of a mile south of this bluff the dip is 80° towards S. 70° W.

On going east from the south end of the lake to the small lake which is crossed by the south line of sec. 30, east of the quarter post, only a few outcrops were seen. These were of the same slate formation as exists on the shores of Wind lake. On the west shore of this small lake the strike is N. 20° W. and the dip 80° towards S. 70° W., but at an outcrop about an eighth of a mile west of this the strike is N. 25° E. and the dip is probably 80° towards N. 65° W., but the dip could not be accurately determined, as only a smooth glaciated surface was exposed. An outcrop on the east shore of this small lake appears to be of the same slaty formation, but it was not visited. In the E. ½ of N. W. ¼ sec. 30, the altered granite similar to No. 702 is seen.

South of Wind lake a short distance are a few outcrops of the slate formation. Here the beds are twisted somewhat, but the general strike is a little west of north. Southeast from the lake the slate outcrops extend for a quarter of a mile. The dip taken on one outcrop was vertical and the strike N. 25° W. We went east-southeast from the southeast end of Wind lake, but after passing the above mentioned outcrops of slate no other rock was seen *in situ* until coming into about the N. E. ¼ S. W. ¼ sec. 32, T. 66–5. Here the ordinary coarse grained hornblende granite occurs, but of not quite as coarse grain as that usually seen on Saganaga lake. Farther on, probably in the S. W. ¼ S. E. ¼ of the same section, granite is again seen.

On going east from Wind lake about the centre of the N. W. ¼ sec. 30, an apparent gradation is seen between the altered granite and the ordinary granite. The latter was found in the midst of the former and not separated from it by any line or sudden change. Nos. 712 to 716, together with the finer grained conditions of this rock already described, show this gradation into the ordinary granite. In its coarsest condition the altered granite is much weathered and decayed, and it is difficult to get good specimens of it. I also went east from the lake a short distance on the north line of sec. 30, and then northeast to the bay of Saganaga lake in the S. W. ¼ sec. 19, T. 66–5, and saw essentially the same gradations. In places the altered granite has irregular areas in which the large quartz grains are lacking and the rock is almost entirely composed of a fine greenish material, as seen in specimens Nos. 688 and 689. In a few places the large quartz grains were arranged along definite, distinct lines or "beds," and this arrangement faded off into the main mass of the rock where no arrangement of the grains could be seen. These "beds" ran from 10° to 30° W. of N. and seemed to stand vertical.

PART II.—CATALOGUE OF ROCK SPECIMENS

COLLECTED BY ULYSSES SHERMAN GRANT IN 1891.

This is a continuation of the list ended on page 215 of the 17th (1888) Annual Report. The page references refer to the places where the specimens are described in this report.

KAWISHIWI RIVER AREA.

299. Greenstone. Just south of Pickerel lake, on the east line of sec. 25, T. 63–11. P. 39.

300. Quartzless porphyry. A short distance south of the last. P. 39.

301. Contact of the last with the greenstone. Same locality. P. 39.

302. Greenstone. S. E. ¼ N. W. ¼ sec. 25, T. 63–11, portage from Kawishiwi river to Pickerel lake. P. 39.

303. Schistose graywacke. Same locality. P. 39.

304. Greenstone. S. E. ¼ N. W. ¼ sec. 25, T. 63–11, Pickerel lake. P. 39.

305. Greenstone. N. W. ¼ N. E. ¼ sec. 25, T. 63–11, south shore of Pickerel lake. P. 39.

306. Siliceous greenstone. N. W. ¼ N. E. ¼ sec. 25, T. 63–11, south shore of Pickerel lake. P. 39.

307. Greenstone. N. E. ¼ N. W. ¼ sec. 30, T. 63–10, south shore of Pickerel lake, at the outlet. P. 39.

308. Greenstone. N. E. ¼ N. W. ¼ sec. 30, T. 63–10, east end of Pickerel lake. P. 39.

309. Greenstone. S. W. ¼ S. W. ¼ sec. 19, T. 63–10, north shore of Pickerel lake. P. 39.

310. Sericitic schist. East line of sec. 19, T. 63–11, north of the quarter post. P. 39.

311. Coarse gneissic syenite. A short distance farther south and just north of the quarter post. P. 39.

312. Fine granite. Same locality. P. 39.

313. Dark gneissic syenite. East line of sec. 19, T. 63–11, south of the quarter post. P. 39.

314. Mica-schist. Same locality. P. 39.

315. Fine biotite granite vein rock. Same locality. P. 40.

316. Mica-schist. S. W. ¼ N. W. ¼ sec. 30, T. 63–10, little point on north side of the Kawishiwi river. P. 40.

317. Fine vein granite. Same locality. P. 40.

318. Mica-schist. South of the Kawishiwi river, about on the west line of sec. 31, T. 63–10. P. 43.

319. Green schist. Same locality. P. 43.

320. Red syenite. N. E. ¼ S. W. ¼ sec. 30, T. 63–10, south shore of the Kawishiwi river. P. 43.

321. Dyke rock in the syenite. Same locality. P. 44.

322 to 325. Syenite near the contact with the mica-schist. Same locality. P. 44.

326 to 328. Mica-schist near the contact with the syenite. Same locality. P. 44.

329. Syenite and mica-schist in contact; not *in situ*. Same locality. P. 44.

330. Fine diorite dyke rock. S. W. ¼ N. E. ¼ sec. 30, T. 63–10. P. 44.

331. Hornblende gneiss; inclusion in syenite. Same locality. P. 44.

332. Siliceous schist; inclusion in syenite. Same locality. P. 44.

333 to 336. Specimens showing change from mica-schist to syenite. S. E. ¼ N. E. ¼ sec. 30, T. 63–10, east shore of Kawishiwi river. P. 44.

337. Syenite showing "flowage structure." S. W. ¼ N. W. ¼ sec. 32, T. 63–10, south shore of Clearwater lake. P. 40.

338. Red syenite. Same locality. P. 40.

339. Coarse syenite. S. W. ¼ S. E. ¼ sec. 29, T. 63–10, north shore of Clearwater lake. P. 40.

340. Fine syenite. West line of sec. 32, T. 63–10, north shore of Clearwater lake. P. 41.

341. Mica-schist and syenite in contact. N. E. ¼ N. E. ¼ sec. 31, T. 63–10, north shore of Clearwater lake. P. 41.

342. Red syenite near contact with mica-schist. Same locality. P. 42.

343. Coarse black diorite. E. ½ N. E. ¼ sec. 31, T. 63–10, west shore of Clearwater lake. P. 41.

344. Red syenite cutting the above diorite. Same locality. P. 41.

345. Gray syenite cutting the above diorite. Same locality. P. 41.

346. Trap dyke rock. Same locality. P. 41.

347 and 348. Red syenite. West line of sec. 5, T. 62–10, north of the Kawishiwi river. P. 41.

349. Hornblende vein rock. Same locality. P. 41.

350. Dark red syenite. Near the west line of sec. 5, T. 62–10, north shore of the Kawishiwi river. P. 42.

351. Dark coarse syenite. Same locality. P. 42.

352 to 354. Coarse dark diorite. S. W. ¼ N. W. ¼ sec. 5, T. 62–10, north shore of the Kawishiwi river. P. 42.

355. Syenite. S. E. ¼ N. E. ¼ sec. 5, T. 62–10, Kawishiwi river. P. 42.

356. Red hornblende granite. N. W. ¼ S. W. ¼ sec. 9, T. 62–10, south shore of the Kawishiwi river. P. 42.

357. Gabbro. S. W. ¼ S. W. ¼ sec. 9, T. 62–10. P. 42.

358. Fine grained biotite granite. Same locality. P. 42.

359. Biotite syenite. Same locality. P. 42.

360. Red aplite. Same locality. P. 42.

361. Fine micaceous syenite. S. W. ¼ sec. 9, T. 62–10, east shore of the Kawishiwi river. P. 42.

362. Fine gray syenite. Same locality. P. 42.

363 and 364. Intermediate between gabbro and syenite. Same locality. P. 42.

365. Purple porphyrite (?). Same locality. P. 43.

366. Dark syenite. Sec. 34 (?), T. 63–10, west shore of the Kawishiwi river. P. 43.

367. Syenite. Same locality. P. 43.

368. Coarse syenite. S. W. ¼ sec. 34, T. 63–10, west shore of the Kawishiwi river. P. 43.

369. Coarse diorite. Just north of the centre of sec. 26, T. 63–10, south shore of the Kawishiwi river. Pp. 44–45.

370. Trap dyke rock. Same locality. P. 45.

371. Fine red granite. Same locality. P. 45.

372. Fine gray granite. Just west of the last. P. 45.

373. Diorite. Same locality. P. 45.

374. Diorite and granite in contact. Same locality. P. 45.

375. Coarse diorite. S. W. ¼ sec. 26, south shore of the Kawishiwi river. P. 45.

376. Diorite, fine grained. N. W. ¼ S. W. ¼ sec. 26, T. 63–10, south shore of the Kawishiwi river. P. 45.

377. Coarse red syenite. S. W. ¼ S. W. ¼ sec. 26, T. 63–10, south shore of the Kawishiwi river. P. 45.

378. Gneiss inclusion in the syenite. Same locality. P. 45.

379. Greenstone. West line of sec. 22, T. 63–10, north of the Kawishiwi river. P. 45.

380. Greenstone. Same locality. P. 45.

381. Quartz porphyry. Same locality. P. 45.

382. Greenstone. West line of sec. 22, T. 63–10, ¾ mile north of the Kawishiwi river. P. 46.

383. Fine graywacke. N. E. ¼ N. E. ¼ sec. 28, T. 63–10, north shore of the Kawishiwi river. P. 46.

384. Coarser graywacke. Same locality. P. 46.

385. Coarse graywacke. N. E. ¼ N. E. ¼ sec. 28, T. 63–10, north shore of the Kawishiwi river. P. 46.

386. Finer graywacke; Same locality. P. 46.

387. Gneissic syenite. N. E. ¼ N. E. ¼ sec. 28, T. 63–10, portage along north side of the Kawishiwi river. P. 46.

388. Fissile greenstone. N. W. ¼ N. E. ½ sec. 28, T. 63–10, portage along north side of the Kawishiwi river. P. 46.

389 to 394. Specimens illustrating passage from greenstone to syenite. Same locality. P. 47.

395. Finely jointed greenstone. Same locality. P. 47.

395A. Sericitic graywacke. N. E. ¼ N. W. ¼ sec. 28, T. 63–10, portage along the north side of the Kawishiwi river. P. 47.

396. Contact of graywacke and syenite. Same locality. P. 47.

397 to 400. Facies of the syenite near the contact. Same locality. P. 47.

401. Greenstone. Same locality. P. 47.

402. Quartz porphyry from edge of dyke. N. ½ N. W. ¼ sec. 28, T. 63–10, north shore of the Kawishiwi river. P. 48.

403. The same from center of dyke, Same locality. P. 48.

404. Gray gniess. S. E. ¼ N. W. ¼ sec. 28, T. 63–10, south of the Kawishiwi river. P. 48.

405. Sericitic schist. Same locality. P. 49.

406 to 408. Gray gneiss. Same locality. P. 49.

409. Diorite in the gneiss. Same locality. P. 49.

410. Red syenite. N. E. ¼ N. E. ¼ sec. 29, T. 63–10, north shore of the Kawishiwi river. P. 49.

411. Quartzporphyry. N. ½ N. E. ¼ sec, 29, T. 63–10, north shore of the Kawishiwi river. P. 49.

412. Greenstone. West line of sec. 21, T. 63–10, one-eighth mile north of the S. W. corner of this section. P. 56.

413. Gray granite porphyry. N. W. ¼ S. E. ¼ sec. 20, T. 63–10, west shore of lake. P. 56.

414. Quartzporphyry (?). N. W. ¼ N. E. ¼ sec. 21, T. 63–10, north shore of lake. P. 56.

415. Greenstone near dyke walls. N. ½ N. E. ¼ sec. 21, T. 63–10, south shore of lake. P. 57.

416. Quartz porphyry at edge of dyke. Same locality. P. 57.

417. The same from center of dyke. Same locality. P. 57.

418. Greenstone. South line of sec. 16, T. 63–10, north shore of lake. P. 57.

419. Magnetite slate. East line of sec. 16, T. 63–10, a short distance north of the quarter post. P. 58.

420 to 422. Sericitic gneiss near syenite contact. Near the west line of sec. 28, T 63–10, one-third mile south of the Kawishiwi river. P. 50.

423. Gneiss and syenite in contact. Same locality. P. 50.

424. Gneissic syenite near the contact with the gneiss. Same locality. P. 50.

425. Red syenite. Same locality. P. 50.

426. Sericitic schist. Near the west line of sec. 29, T. 63–10, south of the Kawishiwi river. P. 50.

427. Mica-schist. Same locality. P. 50.

428. Syenite porphyry (?). N. ½ N. W. ¼ sec. 29, T. 63–10, north of the Kawishiwi river. P. 51.

429 to 431. Gray gneiss. Small island in the bay in the N. W. ¼ N. W. ¼ sec. 27, T. 63–10, Kawishiwi river. P. 51.

432. Reddish syenite. Same locality. P. 51.

433. Schist inclusion in syenite. Same locality. P. 51.

434. Mica-schist from inclusion in syenite. East shore of the same bay. P. 51.

435 Mica-schist and syenite in contact. Same locality. P. 51.

436. Schistose syenite. S. E. corner of bay in N. E. ¼ N. W. ¼ sec 27, T. 63–10, Kawishiwi river. P. 51.

437. Gneissic syenite (?). Same locality. P. 51.

438. Gneiss. Same locality. P. 51.

439. Granite vein rock. Same locality. P. 52.

440. Schistose syenite. N. ½ sec. 27, T. 63–10, north shore of the Kawishiwi river. P. 52.

441. Chloritic syenite. Same locality. P. 52.

442. Dark gneiss. N. E. ¼ N. E. ¼ sec. 27, T. 63–10, north shore of the Kawishiwi river. P. 53.

443 and 444. Sericitic gneiss. N. W. ¼ N. W. ¼ N. W. ¼ sec. 26, T. 63-10, north shore of the Kawishiwi river. P. 53.

445. Gray hornblende gneiss. Same locality. P. 53.

446. Gneiss and green inclusion. Same locality. P. 53.

447. Mica-schist. N. W. ¼ N. W. ¼ sec. 26, T. 63–10, north shore of the Kawishiwi river. P. 53.

448. Greenstone inclusion in syenite. N. W. ¼ N. W. ¼ sec. 26, T. 63–10, north of the Kawishiwi river. P. 54.

449. Schistose greenstone. Same locality. P. 54.

450. Diorite. East shore of the bay which is crossed by the south line of sec. 23, T. 63–10, Kawishiwi river. P. 54.

451. Diorite and syenite in contact. Same locality. P. 54.

452. Pegmatite. Same locality. P. 54.

453 to 455. Siliceous schist. N. E. ¼ S. W. ¼ sec. 24, T. 63–10, portage from the Kawishiwi river to Triangle lake. P. 58.

456. Greenstone. Same locality. P. 58.

457. Green slate. S. E. ¼ N. W. ¼ sec. 24, T. 63–10, same portage. P. 58.

458. Altered quartz porphyry. 'N. E. ¼ N. W. ¼ sec. 13, T. 63–10, south side of small island in Northwest lake. P. 58.

459. Mottled greenstone. N. E. ¼ N. E. ¼ sec. 13, T. 63–10, north shore of Northwest lake. P. 58.

460. Gabbro and biotite syenite in contact. N. W. ¼ sec. 25, T. 63–10, south shore of the Kawishiwi river. P. 55.

461. Gray syenite. Same locality. P. 55.

462. Red syenite. Same locality. P. 55.

463. Gray syenite. Sec. 26, T. 63–10, Kawishiwi river. P. 55.

464 to 466. Rock intermediated between syenite and gabbro. N. ½ S. W. ¼ sec. 19, T. 62–9, island in the Kawishiwi river. P. 55.

467. Syenite. Same locality. P. 55.

468. Gabbro. N. ½ S. W. ¼ sec. 19, T. 63–9, south shore of the Kawishiwi river. P. 55.

469. Syenite. Same locality as No. 467. P. 55.

470. Rock intermediade between gabbro and syenite. Near the center of sec. 19, T. 63–9, point on north side of the Kawishiwi river. P. 55.

471 and 472. Greenstone. S. E. ¼ N. W. ¼ sec. 19, T. 63–9, north shore of the Kawishiwi river. P. 56.

473. Diorite. West line of sec. 20, T. 63–9, north of the Kawishiwi river. P. 56.

SNOWBANK LAKE AREA.

474. Coarse syenite. Sec. 11, T. 63–9, portage from the Kawishiwi river to Snowbank lake. P. 60.

475. Fine red syenite. Same locality. P. 60.

476. Syenite. Same locality. P. 60.

477. Diorite. Same locality. P. 60.

478. Fine syenite. Same locality. P. 60.

479. Fine diorite. Same locality. P. 60.

480 and 481. Gray porphyritic syenite. Same locality. P. 60.

482. Fine syenite. N. ½ N. E. ¼ sec. 11, T. 63–9, west shore of Snowbank lake. P. 60.

483. Dark red syenite. S. ½ S. E. ¼ sec. 2, T. 63–9, west shore of Snowbank lake. P. 60.

484. Gray Syenite. Same locality. P. 60.

485. Syenite. N. W. ¼ S. E. ¼ sec. 2, T. 63–9, island in Snowbank lake. P. 60.

486. Reddish syenite vein rock. Same locality. P. 60.

487. Diorite. West line of sec. 36, T. 64–9, south shore of Snowbank lake. P. 61.

488. Coarse syenite. S. E. ¼ sec. 35, T. 64–9, south shore of Snowbank lake. P. 61.

489. Fine syenite. S. E. ¼ N. W. ¼ sec. 35, T. 64–9, south shore of Snowbank lake. P. 61.

489A. Fine diabase. S. E. ¼ S. E. ¼ sec. 27, T. 64–9, west shore of Snowbank lake. P. 61.

490. Syenite porphyry. Same locality. P. 61.

491. Fine reddish hornblende granite. North line of sec. 35, T. 64–9, west shore of Snowbank lake. P. 62.

492. Mica-schist. N. E. ¼ N. W. ¼ sec. 35, T. 64–9, west shore of Snowbank lake. P. 62.

493. Gneiss. Same locality. P. 62.

494 and 495. Gneiss near granite contact. Same locality. P. 62.

496. Gneiss and granite in contact. Same locality. P. 62.

497. Syenite porphyry. S. E. ¼ S. W. ¼ sec. 26, T. 64–9, west shore of Snowbank lake. P. 63.

498. Hornblende granite. S. E. ¼ S. W. ¼ sec. 26, T. 64–9, island in Snowbank lake. P. 63.

499. Gray biotite gneiss. S. E. ¼ S. W. ¼ sec. 26, T. 64–9, west shore of Snowbank lake. P. 64.

500. Syenite porphyry from centre of dyke. Same locality. P. 64.

501. The same from edge of dyke. Same locality. P. 64.

502. Hard green schist. N. W. ¼ S. W. ¼ sec. 26, T. 64–9, west shore of Snowbank lake. P. 65.

502A. Gneiss from pebble in the schist. Same locality. P. 65.

503. Fine hornblende granite. Same locality. P. 65.

504. Porphyrite. N. W. ¼ S. W. ¼ sec. 26, T. 64–9, west shore of Snowbank lake. P. 65.

505. Schistose condition of the same. Same locality. P. 65.

506. Fine syenite dyke rock. Same locality. P. 65.

507. Mottled diorite. S. W. ¼ N. E. ¼ sec. 26, T. 64–9, west shore of Snowbank lake. P. 65.

508. Greenstone. Same locality. P. 65.
509. Red syenite. Same locality. P. 65.
510. Greenstone. Same locality. P. 65.
511. Mica-schist. N. E. ¼ sec. 26, T. 64–9, west shore of Snowbank lake. P. 65.
512. Green schist. Same locality. P. 65.
513. Hornblende granite. Same locality. P. 66.
514. Graywacke. Near the north line of sec. 26, T. 64–9, west shore of Snowbank lake. P. 66.
515. Siliceous schist. S. E. ¼ S. E. ¼ sec. 23, T. 64–9, west shore of Snowbank lake. P. 66.
516. Green schist. Sec. 24, T. 64–9, north shore of Snowbank lake. P. 66.
517. Siliceous schist. Same locality. P. 66.
518. Hornblende granite. East line of sec. 24, T. 64–9, north shore of Snowbank lake. P. 66.
519. Contact of schist and granite. Same locality. P. 66.
520. Siliceous mica-schist near granite contact. Same locality. P. 66.
521. Fine dark syenite. Same locality. P. 66.
522. Syenite. N. E. ¼ S. W. ¼ sec. 19, T. 64–8, island in Snowbank lake. P. 66.
523. Light gray syenite. N. W. ¼ S. W. ¼ sec. 29, T. 64–8, east shore of Snowbank lake. P. 66.
524. Coarse biotitic syenite. Near south line of sec 30, T. 64–8, east shore of the largest island in Snowbank lake. P. 67.
525. Biotite gneiss. N. W. ¼ N. E. ¼ sec. 31, T. 64–8, south end of island in Snowbank lake. P. 67.
526. Reddish syenite. N. E. ¼ sec. 1, T. 63–9, portage from Snowbank to Round lake. P. 67.
527. Mica-schist cut by syenite veins. N. E. ¼ S. E. ¼ sec. 1, T. 63-9, north shore of Round lake. P. 67.
528 and 529. Gneiss. N. E. ¼ S. E ¼. sec. 1, T. 63–9, west shore of Round lake. P. 67.
530. Fine red syenite. Same locality. P. 67.
531 and 532. Gneiss. Same locality. P. 67.
533. Brown syenite (?). N. E. ¼ N. W. ¼ sec. 7, T. 63–8, south shore of Round lake. P. 67.
534. Fine red syenite. E. ½ sec. 6, T. 63–8, east shore of Round lake. P. 68.
535. Syenite and fine gabbro (?) in contact. N. W. ¼ N. E. ¼ sec. 7, T. 63–8, south shore of Round lake. P. 68.
536. Fine gabbro (?). Same locality. P. 68.

537. Gabbro. Same locality. P. 68.

538. Gray syenite (?). S. ½ S. W. ¼ sec. 32, T. 64–8, portage between Disappointment and Snowbank lakes. P. 68. [Note: No. 539, on p. 68, should be No. 538.]

539. Fine red syenite. Same locality. P. 69.

KEKEQUABIC LAKE AREA.

540. Soft green biotite schist. N. E. ¼ N. W. ¼ sec. 11, T. 64–7, portage south of Kekequabic lake. P. 69.

541. Fine gabbro (?). W. ½ sec. 11, T. 64–7, west end of River lake. P. 69.

542. Finer facies of the same. N. E. ¼ S. E. ¼ sec. 11, T. 64–7, portage from River to Shoofly lake. P. 69.

543. Streaks of biotite in the same. S. E. ¼ N. W. ¼ sec. 11, T. 64–7, River lake. P. 69.

544. Greenstone from the fine gabbro (?). S. E. ¼ N. W. ¼ sec. 11, T. 64–7, River lake. P. 69.

545. Fragments of syenite in the fine gabbro (?). Same locality. P. 69.

546. Gray syenite. N. E. ¼ S. W. ¼ sec. 11, T. 64–7, south shore of River lake. P. 69.

547. Fine biotitic gabbro (?). S. E. ¼ N. W. ¼ sec. 11, T. 64–7, east shore of River lake. P. 70.

548. Fine gray gabbro (?). Same locality. P. 70.

549. Pyroxene granite. S. E. ¼ S. W. ¼ sec. 2, T. 64–7, south shore of Kekequabic lake. P. 70.

550. Diorite (?). S. E. ¼ S. W. ¼ sec. 3, T. 64–7, south shore of Kekequabic lake. P. 71.

551. Porphyritic pyroxene granite. S. W. ¼ S. W. ¼ sec. 3, T. 64–7, south shore of Kekequabic lake. P. 71.

552. Hardened black slate. Same locality. P. 71.

553. Pyroxene granite. S. W. ¼ N. W. ¼ sec. 3, T. 64–7, west shore of Kekequabic lake. P. 71.

554. Contact of diorite and granite. Same locality. P. 71.

555. Diorite. Same locality. P. 71.

556. Pyroxene granite. Same locality. P. 72.

557. Finer facies of the same. Same locality. P. 72.

558. Granite porphyry (?). S. W. ¼ N. W. ¼ sec. 3, T. 64–7, small island in Kekequabic lake. P. 72.

559. Black argillyte. Same locality. P. 72.

560. Granite porphyry. Same locality. P. 72.

561. Coarse diorite. S. W. ¼ N. W. ¼ sec. 3, T. 64–7, small island in Kekequabic lake. P. 73.

562. Finer diorite. Same locality. P. 73.
563. Spotted black argillyte. S. W. ¼ N. W. ¼ sec. 3, T. 64–7, west shore of Kekequabic lake. P. 73.
564. Green schist. S. E. ¼ N. W. ¼ sec. 4, T. 64–7, west shore of Kekequabic lake. P. 73.
565. Fine pyroxene granite. S. E. ¼ N. W. ¼ sec. 3, T. 64–7, small island in Kekequabic lake. P. 73.
566. Coarser pyroxene granite. Another island in the same $\frac{1}{16}$ section. P. 73.
567. Fine dark facies of the granite (?). S. W. ¼ N. E. ¼ sec. 3, T. 64–7, north shore of largest island in Kekequabic lake. P. 73.
568. Black slate in the granite. Same locality. P. 73.
569. Chloritic conglomerate. N. E. ¼ N. W. ¼ sec. 11, T. 64–7, east shore of Kekequabic lake. P. 73.
570. Green schist. Same locality. P. 74.
571. Fine pyroxene granite. S. W. ¼ S. E. ¼ sec. 2, T. 64–7, just east of Kekequabic lake. P. 74.
572. Inclusion in the granite. Same locality. P. 74.
573. Porphyritic pyroxene granite. N. W. ¼ N. W. ¼ sec. 2, T. 64–7, small island in Kekequabic lake. P. 74.
574. Mica diorite (?). Same locality. P. 74.
575. Contact of the last two. Same locality. P. 74.
576. Fine pyroxene granite. S. W. ¼ S. E. ¼ sec. 35, T. 65–7, south shore of Kekequabic lake. P. 74.
577. Pyroxene granite porphyry. S. E. ¼ S. E. ¼ sec. 35, T. 65–7, south shore of Kekequabic lake. P. 74.
578. Purple granite porphyry. Same locality. P. 74.
579. Fine pyroxene granite. S. E. ¼ S. W. ¼ sec. 36, T. 65–7, just south of Kekequabic lake. P. 75.
580. Granite porphyry at contact with conglomerate. S. ½ N. E. ¼ sec. 36, T. 65–7, south shore of Kekequabic lake. P. 75.
581. Conglomerate at contact with granite porphyry. Same locality. P. 75.
582. Granite porphyry. Same locality. P. 75.
583. Granite porphyry carrying biotite. N. ½ S. W. ¼ sec. 36, T. 65–7, Stacy island, Kekequabic lake. P. 76.
584. Fine diabase. S. E. ¼ N. E. ¼ sec. 36, T. 65–7, northeast shore of small lake. P. 81.
585. Granite porphyry. Same locality. P. 81.
586. Granite porphyry. Same locality. P. 81.
587. The same from contact with diabase. Same locality. P. 81.
588. Granite porphyry. S. E. ¼ N. E. ¼ sec. 36, T. 65–7, north shore of small lake. P. 81.

589. Fine pyroxene granite. N. W. ¼ S. E. ¼ sec. 36, T. 65–7, west shore of small lake. P. 81.

590. Fine pyroxene granite. A short distance south of the last. P. 81.

591. Gray granite porphyry. N. E. ¼ S. E. ¼ sec. 36, T. 65–7, south shore of small lake. P. 82.

592. Inclusion in granite porphyry. N. E. ¼ S. E. ¼ sec. 36, T. 65–7, east shore of small lake. P. 82.

593. Metamorphosed conglomerate. S. W. ¼ N. W. ¼ sec. 31, T. 65–6, south shore of Kekequabic lake. P. 76.

594. Metamorposed conglomerate. N. E. ¼ S. W. ¼ sec. 31, T. 65–6, south shore of Kekequabic lake. P. 76.

594A. Pebbles from the same. Same locality. P. 76.

595. Metamorphosed conglomerate. S. E. ¼ N. E. ¼ sec. 31, T. 65–6, south shore of Kekequabic lake. P. 76.

596. Granite porphyry. E. ½ S. E. ¼ N. E. ¼ sec. 31, T. 65–6, south shore of Kekequabic lake. P. 77.

597. Granite porphyry at contact with diabase. Same locality. P. 77.

598. Fine diabase at contact with granite porphyry. Same locality. P. 77.

599. Fine diabase. Same locality. P. 77.

600. Coarser condition of the same. Same locality. P. 77.

601 to 615. Specimens showing gradations from a gray slate (?) to the pyroxene granite. S. W. ¼ N. W ¼ sec. 3, T. 64–7, west shore of Kekequabic lake. P. 72.

616. Granite porphyry. W. ½ N. E. ¼ N. W. ¼ sec. 31, T. 65–6, north shore of Kekequabic lake. P. 77.

617. Granite porphyry near contact with greenstone. Same locality. P. 77.

618. Greenstone near contact with granite porphyry. Same locality. P. 77.

619. Greenstone. Same locality. P. 77.

620. Inclusion in granite porphyry. Same locality. P. 77.

621. Granite porphyry. S. W. ¼ S. W. ¼ sec. 29, T. 65–6, north shore of Kekequabic lake. P. 77.

621A, 621B and 621C. Inclusions in granite porphyry. N. W. ¼ N. W. ¼ sec. 32, T. 65–6, north shore of Kekequabic lake. P. 77.

622. Purple slate. N. E. ¼ S. W. ¼ sec. 36, T. 65–7, south shore of Kekequabic lake. P. 78.

623. Pyroxene granite. Same locality. P. 78.

624. Pyroxene granite at contact with purple slate. Same locality. P. 78.

625. Purple slate at contact with granite. Same locality. P. 78.
626. Hardened slate (?). Same locality. P. 78.
627. Gray slate. Same locality. P. 78.
628. Granite porphyry at contact with greenstone. N. E. ¼ N. E. ¼ sec 36, T. 65–7, north shore of Kekequabic lake. P. 78.
629. Granite porphyry. Same locality. P. 78.
630. Metamorphosed conglomerate. N. W. ¼ S. E. ¼ sec. 31, T. 65–6, south of Kekequabic lake. P. 79.
631. Black slate. N. W. ¼ S. E. ¼ sec. 31, T. 65–6, south of Kekequabic lake. P. 79.
632. Grit. S. W. ¼ S. E. ¼ sec. 31, T. 65–6. P. 79.
633. Grit and slate interbanded. Same locality. P. 79.
634. Grit. N. W. ¼ N. E. ¼ sec. 6, T. 64–6. P. 79.
635. Grit. S. W. ¼ S. E. ¼ sec. 6, T. 64–6. P. 79.
636. Granite porphyry (?). S. W. ¼ N. E. ¼ sec. 7, T. 64–6. P. 80.
637. Green conglomerate. N. E. ¼ S. W. ¼ sec. 7, T. 64–6, north of small lake. P. 80.
638. Crystalline conglomerate. S. E ¼ S. W. ¼ sec. 7, T. 64–6, just north of small lake. P. 80.
639. Gabbro. S. ½ S. E. ¼ sec. 7, T. 64–6, east shore of small lake. P. 80.
640. Porphyritic (?) conglomerate. S. E. ¼ S. E. ¼ sec. 29, T. 65–6, east end of portage. P. 82.
641. Green conglomerate. Same locality. P. 82.
642. Metamorphosed grit (?). S. W. ¼ S. W. ¼ sec. 26, T. 65–6, east shore of small lake. P. 82.
643. Fine diabase. Same locality. P. 82.
644. Metamorphosed grit (?) at contact with diabase. Same locality. P. 82.

Saganaga lake area.

645. Coarse gray granite. N. E. ¼ N. W. ¼ sec. 17, T. 65–5, West Sea Gull lake. P. 83.
646. Decayed granite. Same locality. P. 83.
647. Coarse granite. N. E. ¼ N. E. ¼ sec. 17, T. 65–5. P. 83.
648. Green slate. N. W. ¼ N. E. ¼ sec. 17, T. 65–5, south shore of West Sea Gull lake. P. 83.
649. Coarse granite vein rock. Same locality. P. 83.
650. Fine reddish granite vein rock. Same locality. P. 83.
651. Greenstone. N. E. ¼ N. W. ¼ sec. 17, T. 65–5, south shore of West Sea Gull lake. P. 83.
652. Diabase. Same locality. P. 83.

653. Fine graywacke. S. W. ¼ S. W. ¼ sec. 8, T. 65–5, west shore of West Sea Gull lake. P. 84.

654. Ogishke Muncie conglomerate. N. W. ¼ S. W. ¼ sec. 8, T. 65–5, west shore of West Sea Gull lake. P. 84.

655. Granite. N. E. ¼ S. E. ¼ sec. 7, T. 65–5, just west of West Sea Gull lake. P. 84.

656. Ogishke Muncie conglomerate at contact with granite. N. W. ¼ N. E. ¼ S. E. ¼ sec. 8, T. 65–5. P. 84.

657. Granite at contact with conglomerate. Same locality. P. 84.

657A. Granite. Same locality. P. 84.

658. Matrix of conglomerate. Same locality. P. 84.

659. Fine green matrix of conglomerate. Same locality. P. 85.

660. Purple porphyrite (?) at contact with granite. N. ½ S. W. ¼ N. W. ¼ sec. 8, T. 65–5, west shore of West Sea Gull lake. P. 85.

661. Purple porphyrite (?). Same locality. P. 85.

662. Diabase from dyke. N. W. ¼ S. W. ¼ sec. 5, T. 65–5, west shore of West Sea Gull lake. P. 85.

663. Green slate. E. ½ N. E. ¼ S. E. ¼ sec. 6, T. 65–5. P. 85.

664. Grit. Same locality. P. 85.

665. Granite. W. ½ N. W. ¼ N. W. ¼ sec. 8, T. 65–5, west shore of small lake. P. 86.

666. Decayed granite. W. ½ N. W. ¼ N. W. ¼ sec. 8, T. 65–5, just west of small lake. P. 86.

667. Decayed granite. Same locality. P. 87.

668. Decayed granite (?). Same locality. P. 87.

669. Hardened mica-schist. E. ½ S. E. ¼ N. E. ¼ sec. 17, T. 65–5, west shore of small lake. P. 87.

670. Green siliceous schist. S. ½ S. W. ¼ N. W. ¼ sec. 16, T. 65–5, south shore of small lake. P. 87.

671. Decayed granite. West line of sec. 15, T. 65–5, south shore of Sea Gull lake. P. 88.

672. Fine gray granite. West line of sec. 15, T. 65–5, just north of the southwest corner of this section. P. 88.

673. Mica-schist. West line of sec. 22, T. 65–5, just south of the northwest corner of this section. P. 88.

674. Quartz porphyry. Same locality. P. 88.

675. Typical hornblende granite. S. W. ¼ S. E. ¼ sec. 8, . 65–5, east shore of small island in West Sea Gull lake. P. 86.

676. Gray fluorite granite. S. E. ¼ N. W. ¼ sec. 14, T. 66–5, island in Saganaga lake. P. 89.

677 and 678. Red fluorite granite. Same locality. P. 89.

679 and 680. Altered granite. N. E. $\frac{1}{4}$ N. W. $\frac{1}{4}$ sec. 14, T. 66-5, south shore of island in Saganaga lake. P. 89.

681. Red aplite at contact with granite. S. E. $\frac{1}{4}$ S. E. $\frac{1}{4}$ sec. 8, T. 66-5, island in Saganaga lake. P. 89.

682. Red aplite. Same locality. P. 89.

683. Coarse hornblende granite. S. $\frac{1}{2}$ S. E. $\frac{1}{4}$ sec. 18, T. 66-5, island in Saganaga lake. P. 90.

684. Altered granite. S. E. $\frac{1}{4}$ N. E. $\frac{1}{4}$ S. E. $\frac{1}{4}$ sec. 18, T. 66-5, south shore of Saganaga lake. P. 90.

685. Altered granite. S. W. $\frac{1}{4}$ S. E. $\frac{1}{4}$ sec. 18, T. 66-5, south shore of Saganaga lake. P. 90.

686. Typical coarse hornblende granite. S. W. $\frac{1}{4}$ N. E. $\frac{1}{4}$ sec. 22, T. 66-5, west shore Saganaga lake. P. 88.

687. Altered granite. West line of sec. 19, T. 66-5, south shore of Saganaga lake. P. 90.

688. Green altered granite. Canadian shore, just north of the last. P. 90.

689. Weathered condition of the same. Same locality. P. 90.

690. Altered granite. E. $\frac{1}{2}$ N. E. $\frac{1}{4}$ S. E. $\frac{1}{4}$ sec. 24, T. 66-6, east shore of bay of Saganaga lake. P. 90.

691. Gray slate. Same locality. P. 90.

692 to 694. Altered granite. Same locality. Pp. 90, 91.

695. Graywacke. Same locality. P. 91.

696. Drab fissile slate. Same locality. P. 91.

697. Green slate. S. E $\frac{1}{4}$ N. E. $\frac{1}{4}$ sec. 25, T. 66-6, west shore of Wind lake. P. 93.

698. Graywacke. Same locality. P. 93.

699. Grit. Same locality. P. 93.

700. Graywacke. N. E. $\frac{1}{4}$ S. E. $\frac{1}{4}$ sec. 25, T. 66-6, west shore of Wind lake. P. 93.

701. Slate showing discordance of lamination and slaty cleavage. S. E. $\frac{1}{4}$ S. W. $\frac{1}{4}$ S. W. $\frac{1}{4}$ sec. 30, T. 66-5, just east of Wind lake. P. 93.

702. Altered granite. E. $\frac{1}{2}$ N. W. $\frac{1}{4}$ sec. 30, T. 66-5, east shore of Wind lake. P. 94.

703. Brown fissile slate. Same locality. P. 94.

704. Coarse condition of the same. Same locality. P. 94.

705 to 707. Altered granite (?). S. W. $\frac{1}{4}$ S. W. $\frac{1}{4}$ S. W. $\frac{1}{4}$ sec. 19, T. 65-5, north shore of Wind lake. P. 94.

708. Grit. Same locality. P. 94.

709. Grit (?). Same locality. P. 94.

710. Brown fissile slate. Same locality. P. 94.

711. Grit. S. E. ¼ S. W. ¼ S. W. ¼ sec. 24, T. 66–6, just northwest of Wind lake. P. 94.

712 to 716. Specimens showing gradation from the altered granite to the ordinary granite. N. W. ¼ sec, 30, T. 66–5, east of Wind lake. P. 95.

717 to 725. Specimens showing gradation from the altered granite to the ordinary fresh granite. N. W. ¼ S. W. ¼ sec. 19, T. 66–5, south shore of Saganaga lake. P. 92.

726. Greenstone inclusion in granite. Same locality. P. 92.

727. Altered granite (?). E. ½ S. E. ¼ sec. 24, T. 66–6, east shore of bay of Saganaga lake. P. 91.

728. Graywacke. Same locality. P. 91.

729 to 732. Grit. Same locality. Pp. 91, 92.

733. Altered granite. S. E. ¼ N. E. ¼ sec. 24, T. 66–6, portage from Saganaga lake to Oak lake. P. 92.

734. Altered granite (?). Sec. 24, T. 66-6, south shore of Oak lake. P. 92.

IV.

THE MESABI IRON RANGE.

HORACE V. WINCHELL, F. G. S. A.

CONTENTS.

THE MESABI IRON RANGE.

Discovery of the Ore.

On the sixteenth day of November, 1890, workmen under the direction of Capt. J. A. Nichols, of Duluth, Minnesota, encountered soft hematite in a test-pit on the northwest quarter of section three, township fifty-eight, range eighteen, west of the fourth principal meridian. This mine, now called the Mountain Iron, was the first body of soft ore discovered on the Mesabi iron range. Hard ore, chiefly magnetic, had been known for many years on the Mesabi, and explorations made by Mr. E. W. Griffin, of Minneapolis, near the falls of Prairie river in townships 56–24 and 56–25, had revealed some hard hematite interbedded with quartzyte and low grade soft ore. This, however, was the first merchantable deposit of hematite found on the new range. Capt. Nichols had been doing more or less exploring work along the range for some two years prior to this discovery. The Merritt brothers, of Duluth and Oneota, were not to be discouraged by the reports of explorers and miners added to those of experts and geologists who had condemned the range ever since 1875. To these Duluth pioneers the Mesabi was an attractive and promising district and their faith in it was never shaken, even though their ready cash was spent vainly and two years' searching remained unrewarded. To them belongs the credit for persisting in the hunt for ore and the final discovery of it, and to them rightfully and properly have large rewards already been granted.

What Early Explorers Had Said.

The Mesabi range attracted attention to its iron belt as early as 1875, and several iron experts of good repute were sent to examine the various outcrops of ore known at that time. The journey was an arduous one into a dense wilderness, and there is no wonder they did no test-pitting or drilling. They were sent to examine outcrops which they properly enough condemned, for the only iron to be seen was in thin strata of magnetite banded with jaspery quartzyte, under which, in some places, could be seen the rocks of the Archean.

Professor A. H. Chester, of Hamilton, N. Y., was one who visited the Mesabi in 1875. His account of the ores and rocks there may be found in the eleventh annual report of the Minnesota geological survey, pages 154 to 167.

Capt. A. P. Wood and others were sent to the very property now owned by the Mountain Iron Company, about eight years ago, and seeing nothing but the lean outcrops mentioned above reported adversely on it.

In fact the opinion of these early explorers was unanimously unfavorable to the range. Some of them found the titaniferous ore of the gabbro and drew the hasty conclusion that all the ores on the range would be worthless on account of titanium. The impression gained ground after the mines on the Vermilion range were opened that there was no ore worth mining on the Mesabi, because it consisted of nearly horizontal strata, or, in miner's parlance, was a "blanket formation." The ore deposits in the ranges on the south shore of lake Superior are all inclined at high angles, and a flat deposit of ore of any considerable purity and thickness was unknown in this country. In spite of all this unfavorable opinion on the part of those who should be competent to judge, and against the advice of their friends, the Merritts continued to look for outcrops and dig holes in the ground, and never ceased to dream of hidden stores of iron treasure.

It should here be stated that the opinion of the State Geologist and his assistants was again and again expressed in conversation and put on record in various reports to the effect that the Mesabi was likely to yield large quantities of good ore. It was shown by diagrams that the formation, although a flat one, did contain good ore, and it was indicated where the ore would occur in relation to the other rocks of the range. The order of stratification was studied and explained two or three years before any ore was discovered, and finally we even went so far as to hazard the prediction that the Mesabi range was likely to produce more ore even than the Penokee-Gogebic.*

This and many other statements of similar import put the geological survey on record as favoring the Mesabi, against the opinion of nearly all the actual mine operators and scientists who had examined it.

If the geology of the range as it was described in the annual reports of 1887 and 1888 were better understood by the explorers on the range at the present time there would be fewer test-pits sunk in greenstone, granite and quartzyte and more dollars in the pockets of those who are still vainly searching for ore.

*Bulletin No. 6, p. 160.

It is not the province of the state geological survey to find iron mines; that is the business of the explorer. A geologist's duty is by study and observation to indicate the proper conditions for ore deposits and the geographic limits of the formations in which those conditions may exist. The intelligent and unbigoted explorer will assimilate these ideas and apply them in discovering the stores of hidden wealth. The work of sinking test-pits is work of exploration, not geological work. As soon as a geologist begins to apply his ideas and dig holes he becomes an explorer, and in that work is a geologist no longer. We confess that we take considerable pride in the fact that our predictions in regard to the Mesabi are now in such rapid process of fulfillment.

There are several prominent citizens of Duluth and others who took an early interest in the Mesabi and assisted largely in its rapid development. It is due to their energy and confidence in the new range that there has been begun the exploitation of the greatest iron range in the world, in the most wonderfully rapid and unprecedented fashion. Among these pioneers of development should be mentioned judge J. T. Hale and his partner, E. C. Gridley; A. E. Humphrey, Geo. E. Milligan and others in the firm of A. E. Humphrey & Co., who undoubtedly were engaged in the largest transactions consummated on the range during the first year of its discovery, and whose exertions have resulted in the most extensive discoveries, perhaps several years in advance of the natural process of development; Frank Hibbing, A. J. Trimble, James Billings, John, William and Duncan McKinley, D. T. Adams, J. T. James, Hon. O. D. Kinney, Joseph Sellwood, J. G. Cohoe, P. L. Kimberley, J. T. Jones, J. A. Crowell, James Sheridan, and many others whose names are not now recalled. Judge Hale, especially, through the observations of John McCaskill and B. T. Hale, began exploration work in a systematic and thorough manner. McCaskill's keen eye discovered ore clinging to the roots of an upturned tree on the Cincinnati property, and by tracing out from there the approximate course of the green schist ridges enabled judge Hale and his coöperators to early select and secure possession of some of the best lands in 58–16. The value of clear and accurate observation and shrewd deduction from the facts observed, as to the best location for iron ore deposits and the situations in which they were most likely to occur, was soon made apparent on this range. Those who selected lands by chance, even though they purchased whole sections, did not get as much iron ore as those who applied what knowledge was to be obtained in the selection of promising pieces. The difficulties of becoming acquainted with

such a wilderness and the new conditions to be met with, are incomprehensible to one not familiar with the region, and form some excuse for the great waste of money in the buying of lands and working them during the earlier months. Travel was perforce on foot, and supplies were carried on men's backs through swamps and dense forests for many weary miles. The range of vision is limited in the bushes, and the mantle of glacial drift conceals the rocks, especially the flat formations of the Mesabi. It is no wonder then that a narrow belt of ore should remain undiscovered for so many years in the vast region stretching between Duluth and the Giant's range. Few explorers were hardy and persistent enough to spend the time and undergo the hardships involved in a long search for ore on the much-condemned range. Even after the discovery of large deposits of fine ore it is a matter of great difficulty and expense to take men and supplies into the new regions twelve to forty miles from any railroad. It is highly important that good wagon roads be built through this mining region at once. The roads at present are almost impassable, and the cost of transporting mining outfits enormous, while the delay is a serious matter in many instances. It is a matter of interest to the entire state to have these new ore fields developed, and the first thing to be done is to construct passable roads.

Extent of the Range.

The ore formation of the Mesabi range extends from the Canadian boundary line in Minnesota, in a direction a little south of west to and beyond the Mississippi river in township 56–25, a distance of 140 miles or more. Part of this distance the ore-bearing rocks are concealed from sight by the later gabbro overflow.

The width of the ore belt at any one place probably does not exceed two miles, and will be found to be generally less than one. The ore lies in nearly flat beds, having a variable depth or thickness up to 100 feet. It is not to be inferred that there is a continuous belt of ore half a mile to a mile or more wide and 40–80 feet thick extending for 140 miles on this range. That would be far from true. The ore deposits are found at intervals over this area where the conditions necessary for their formation and accumulation exist. What these conditions are will be explained later. The ore on the eastern end of the range is hard, black and magnetic, all probably owing to the heat of the gabbro overflow. On the central and western portions of the range the ore is soft hematite, limonite and gœthite with hard hematite and limonite streaks of variable thickness.

Ore in merchantable quantity has already been found—June, 1892—on the central part of the range in seven townships, over a length of forty miles. There is good reason to believe it will be found in many places where no work has been done yet, as well as in some sections where hasty or misdirected exploration has so far failed to find it. Township 58-17 especially is likely to produce many more mines.

EXTENT OF OTHER RANGES.

The iron mines worked on the Vermilion range at present are at two points only, Tower and Ely, twenty-three miles apart. Other lake Superior ranges have an extent as follows:

Marquette, from Goose lake to Three lakes, thirty-four miles.

Menominee, from the Breen mine to the Nanaimo, fifty miles.

Penokee-Gogebic, from Sunday lake to Upson on the Wisconsin Central R. R., thirty miles or less.

It is thus evident that there is an opportunity on the Mesabi range, considering merely the area of the iron formation, for a much larger quantity of iron ore than on any other range in the lake Superior district, which is admitted to be the greatest iron district of the globe.

In favorable situations the ore deposits on the Mesabi may have a width of a mile and a length of two miles. The width of ore-bodies here corresponds to the depth on other ranges. Hence there may be in one ore deposit on the Mesabi as much ore within one hundred feet of the surface as on the Vermilion or Marquette range down to the depth of one mile. When this idea is once comprehended and its truth admitted the great advantage of this new range over all other known ranges is at once recognized.

There is always the possibility that the ores of the Mesabi will be found to extend indefinitely to the south under the black slates of the Animikie, and even under the gabbro and trap rocks of the lake Superior basin, until it reappears in the Penokee-Gogebic range on the south shore. In that case the supply of iron which may be counted on for future production is simply incomprehensible and inexhaustible. The greatest and deepest mines of the world will be developed here, and the industry of iron mining and manufacture in this state will continue to grow until iron is no more an article of consumption.

But, while we admit this possibility, we must confess that we do not consider it likely to be the case. The nature of the ore, its probable method of origin as explained later on, its porous texture and hydrated composition, combined with our general geoscopy,

force us to the opinion that the merchantable ore beds are narrow and only locally developed. If here and there ore is found at a considerable depth under the black slates it will be due to some local conditions which cannot be expected to prevail over a wide region, and will be correspondingly accounted for.

Geology of the Mesabi Range.

The geology of the Mesabi has been discussed in the various annual reports of the Minnesota survey which have described field work in the northern part of the state. The U. S. geological survey has also added considerable to the literature of the range and its geology. The views of different geologists, as expressed in these and other publications, will be found referred to in the report on "The Iron Ores of Minnesota," Bulletin No. 6, Geol. and Nat. Hist. Sur. I shall here give merely an outline of the views entertained at present by myself.

Geognosy of the Range.

This iron range presents one of the most interesting chapters in the life-history of that part of the earth's crust which is embraced within the boundaries of Minnesota. We have here the phenomenon of a series of strata, wide-spread and of immense thickness, entirely confined to the south side of a range of granite and syenite hills. Although the country is at the present time much lower, no trace of the Mesabi range rocks has been reported north of the Giant's range granite in this state. The altitude of the various portions of the range is not the same. Elevations or depressions amounting to hundreds of feet have taken place, and the horizontal Taconic strata of the Mesabi have simply sunk or been elevated with the granite and schist which sustain them. On the southern slope of the granite range, whose summits form blue hills visible for thirty miles either south or north, there are accumulated strata of quartzytes, iron slates, quartz slates, cherts and argillytes with flows of gabbro and trap rocks thousands of feet in thickness. Yet only the gabbro eruptives appear to have extended north of the lofty Giant's range, and that very seldom. It is not credible that the Taconic strata once existed north of the granite and have since been entirely swept away by erosion—glacially or otherwise. The sharp, deep gorges in the folded crystalline and earthy schists of the Vermilion range, which lies at the foot of the Giant's range to the north, would surely retain some traces of sediments which formerly filled them. And if the huge granite range was such a protection for the soft ores and slates which lie on its southern

slope as to leave those extensive deposits of soft iron ore, which are now being discovered just beneath the drift mantle, surely there would be some protection afforded to similar rocks by the lesser parallel ridges farther north, and some remnants of the slates would remain.

Look, too, at the difference in the topography on the two sides of the Giant's range, especially west of the gabbro sheet. On the north abrupt ridges and narrow gorges in the vertical eastward-trending folds of the Keewatin; on the south a smooth plain of black slates covered by till, sloping gently southward for fifty miles. North of the granite, on the Duluth and Iron Range railroad, rock-cuts are frequent; south of it, on the Duluth, Missabe and Northern, there is not a rock-cut for forty miles. These differences can be explained in only one way—the limitation of the early Taconic ocean by this granite shore.

Date of the Giant's Range Uplift.

An examination of the granite range, which lies just north of the Mesabi iron belt, makes it evident that the granite hills have been uplifted—undoubtedly without much accompanying metamorphism or other disturbance—since the superincumbent Taconic strata were deposited.

Proof of this is found in the vicinity of Birch lake. Here the quartzyte of the Taconic is seen north of the summit of the Giant's range, but 600 feet below, on the shores of the lake and still confined to the south of the granite belt.

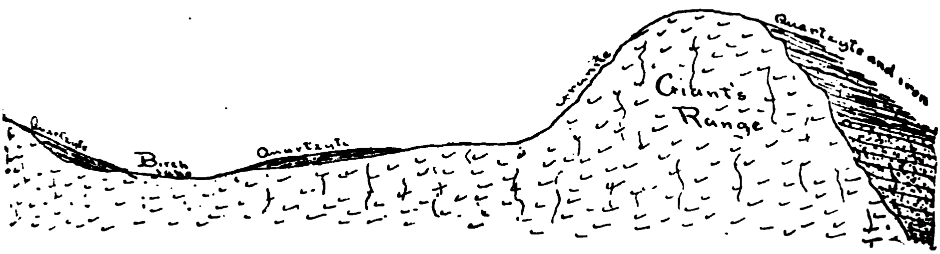


Fig. No. 1. Section from Birch lake to the Mesabi range.

It has been remarked that the quartzyte and magnetite strata which lie on the granite south of Birch lake are almost up to the very summit of the Giant's range.* The force of the ice sheet must have been very strongly felt on this exposed ridge, and erosion would be carried to a greater depth here than elsewhere. The fact that the Taconic strata are still found in such an exposed

*Seventeenth annual report Minn. Survey, p. 85.

situation is proof that the entire ridge was formerly covered by a considerable thickness of these rocks, and must have been elevated in that condition.

At the same time it is true that the fact that the Taconic strata do not extend north of the Giant's range, is an indication that there was a ridge of some sort there during Taconic time. It thus appears probable that the entire region north of the granite may formerly have been higher than now—perhaps even higher than the granite ridge—and has since subsided to its present level. The elevation of the granite hills was thus accompanied by a depression both south and north.

Cause of the Giant's Range Uplift.

In searching for an explanation of the gradual elevation of the Giant's range it is natural to look to the south, towards the lake basin, which is its apparent complement. The immense load of eruptive rock piled up on the north shore of lake Superior could scarcely fail to produce a sinking of the crust in that region. A depression in one part of the crust must be followed or accompanied by a corresponding change in contour and an elevation at some other place. Hence the most natural explanation of the hill range, which now forms the chief water-shed of Minnesota, is in the formation of the lake Superior basin and the outflow of great sheets of trap and gabbro.

These eruptions did not all occur at one time, part of them being found as inter-bedded or laccolitic sheets in the Taconic strata. The upward movement of the range was gradual, corresponding to the gradual accumulation of sediments and flows further south. There is not found in the quarzytes and slates, which now lie upon the granite hills at an elevation of fourteen hundred feet above the water of lake Superior, any stratigraphic deformation or mineralogic alteration which requires the supposition of rapid elevation. From this it follows that the petrographic nature of the Giant's range was practically the same as it is now, at the commencement of Taconic time. Metamorphism intense enough to produce the crystalline rocks of the range, would have had a similar effect on any strata resting upon them. But the slates and other rocks of the Mesabi do not show any evidence of metamorphosing agents aside from the superincumbent gabbro. The stratification is not destroyed, nor disturbed to any considerable extent, while the mineralogical changes observed are more likely to be the result of aqueous than of igneous action.

We have here a simple chain of reasoning from which to infer the solution of the as yet unsettled question of the stratigraphic position of the gabbro:

1st. The elevation of the Giant's range to its present position is post-Taconic.

2nd. The elevation of the Giant's range was caused by the gabbro, hence

3rd. The gabbro is post-Taconic.

This agrees with the observations and conclusions of R. D. Irving in the vicinity of Gunflint and Loon lakes. He has given a section south of these lakes which shows the olivine gabbro lying on top of the Animikie black slates and traps.*

ORDER OF STRATIGRAPHY ON THE MESABI.

The rocks exposed on the Mesabi are the following, in descending order:

1.	Gabbro unconformable on all the following,	Taconic.
2.	Black slates—Animikie, - - - -	Taconic.
3.	Greenish siliceous slates and cherts, -	Taconic.
4.	Iron ore and taconyte horizon, - - -	Taconic.
5.	Quartzyte unconformable on 6 and 7, -	Taconic.
6.	Green schists of the Keewatin, - - -	Archæan.
7.	Granite or syenite of the Giant's range, -	Archæan.

It will be proper to give a brief description of the appearance and occurrence of each of these divisions. It is essential for economical exploration on the range, that these different rock horizons be recognized and distinguished from each other. The object of this sketch of the Mesabi range is more for the purpose of furnishing a reliable and simple account which will be understood and applied in future development, than a scientific discussion of the subject. To the explorer the difference between the green slates of the Taconic and the green schists of the Keewatin is of the utmost importance. The former lie, for the most part, above the ore horizon and the latter entirely beneath it. If he cannot distinguish them at sight he cannot tell which way to direct his line of test-pits, nor when to stop work in any one of them. If he calls the chert "quartzyte," and then concludes that he is below the ore because the quartzyte lies below it, he again makes a mistake and one which may be very costly or result in his missing his ore body entirely. Many similar instances have come under my observation. It is by determining such questions as

*Seventh annual report, U. Geol. Sur., p. 421.

these that geology aids the explorer and miner. Although an elementary knowledge of mineralogy and the composition of the more common rocks would assist in an understanding of the next few paragraphs, yet the principles laid down are so universal and the distinctions so obvious, that it is believed they can be understood and applied by anyone who reads them.

7. Granite of the Giant's Range.

The granite or syenite of the Giant's range lies north of the iron belt of the Mesabi. It forms high rounded ridges of pink or gray crystalline rock. It is composed of rather coarse crystalline grains of gray or flesh-colored feldspar, bluish translucent quartz and black mica or hornblende. It usually possesses no bedded structure and can be broken with almost equal ease in any direction. It is older than the rocks of the iron formation proper, and lies beneath them from the Mountain Iron mine westward.* It has on the north a belt of crystalline mica and hornblende schists, and on the south seems to have a direct transition into

6. Green Schists of the Keewatin.

These schists constitute the rock commonly called "greenstone," or "dioryte" by explorers. They are gray to green in color, softer than the granite and have an earthy appearance instead of a bright crystalline lustre like the mica schists. The green schist has a cleavage which is nearly vertical—when it is not massive. It never occurs in horizontal layers like the quartzyte and slate. The lower bed of the Mesabi ore formation, *i. e.*, the basal quartzyte,—always rests upon this Archæan green schist or upon the granite, and the nature and extent of the ore bodies seem to be entirely independent of the underlying rock.

The green schist does not always follow the course of the granite range. It diverges and forms minor ridges, uplifting the quarzyte and iron strata for a distance of several miles from the main ridge. The presence of these ridges of granite or green schists, whether exposed or not, is one of the essentials to the existence of a body of soft ore, as we shall see later. This green schist is the same as that of the Vermilion iron range, and it is not impossible that lenses of hard iron ore may be discovered in it in some place beneath the ore of the Mesabi. These schists are covered in many places by

5. Quartzyte Unconformable on the Schists and Granite.

This rock is the lowest member of the Taconic strata which constitute the Mesabi iron formation. It is white, gray, green, pink or purple, and is composed of rounded grains of sand, mostly silica. It never has a high dip so far as seen on that portion of the range west of the gabbro overflow. Where it lies upon granite it is pink or white, or may be stained red by iron oxide. Where it rests on green schist it is finer grained, usually in thinner strata and gray or greenish in color. Near the bottom it often contains pebbles of quartz and granite, as well as jasper and greenstone. It has also been observed to contain white or pink mica in horizontal scales as large as half an inch across. In some thin sections the secondary enlargement of the quartz grains is well shown. In others the grains fit closely together and there are few interstitial spaces, although the quartz is crystalline. Where it is found in test-pits under the ore it has usually lost its character of hard vitreous quartzyte for some distance below the contact, and is a soft, coarse, crumbling sandstone, white or iron stained. No merchantable iron ore is found in or below this quartzyte, unless it should be in the green schist, and when this rock is encountered in a test-pit work should be discontinued as quickly as it would be in the granite or green schist. This quartzyte lies immediately under the taconyte horizon.

Its position with reference to the black slates has been a matter of some difference of opinion, and the writer formerly believed it to belong above them. There seems to be no question now, however, that this is the same as the Pewabic quartzyte at Gunflint lake and the Pokegama quartzyte of the Mississippi river, and that it is the lowest member of the Taconic. It has been assigned to the Cretaceous, Potsdam and Huronian by different geologists. Prof. N. H. Winchell believes it to be the equivalent of the Potsdam quartzyte of New York. It occurs at Sioux Falls, South Dakota, and at Baraboo, Wisconsin, in similar association with underlying granite and overlying iron bearing rocks.

4. Iron Ore and Taconyte Horizon.

Resting immediately upon the basal quartzyte, and apparently conformable with it, is a series of strata which present very different appearances in different localities, and which constitute the iron ore deposits in situations favorable for their accumulation. These strata consist of siliceous and sometimes calcareous rocks banded with oxide of iron or iron ore. The ore occurs in streaks

or beds of indefinite length and thickness. It is sometimes magnetite, sometimes hematite, hard or soft. The rock which encloses these bands may be called a jaspery quartzyte, but it contains much besides silica. It is of various colors, but usually gray. It is occasionally cherty, often brecciated and sometimes conglomeritic. There are layers of jasper having a peculiar mottled and streamed appearance; there are others of fine quartz grains more or less mingled with grains of iron oxide; others again are so fine grained as to be flinty, with amorphous silica, which evinces great readiness to dissolve and leave cavities or soft porous streaks in the ledge. In its fresh gray condition one portion of it does not present macroscopically individualized constituents. The silica is clouded with some grayish or greenish element which appears to contain a percentage of lime or iron carbonate. This rock is widely spread over the whole length of the Mesabi, and being different from anything found elsewhere and peculiar to this horizon of the Taconic, has been called *taconyte* by the writer. It has not been studied microscopally or chemically as yet. The examination of specimens now on hand will probably yield further interesting information as to its nature and origin.

This banded jaspery quartzyte or taconyte horizon is not of great thickness. There is a rather abrupt transition below into quartzyte, but a more gradual one into the siliceous slate and chert member above.

The percentage of iron in this rock as it occurs unaltered is seldom sufficient to make it a merchantable ore, though there may be found layers of ore in it thick enough to work profitably like those west of Gunflint lake in T. 65–4. It is not to be expected that there will be any mines of magnetic ore on the central portion of the range. The taconyte, however, is found in all degrees of alteration into good iron ore. The nature of this alteration will be explained later. It is only necessary to add here that this is the horizon to follow in the search for ore. It is the rock which contains and produces the ore, and test-pits which reveal this member of the Taconic formation are not discouraging. Having found it the next thing is to find some uniform, even slope of considerable descent and let the test-pits follow it down, be it north, east, south or west.

3. Greenish Siliceous Slates and Cherts.

These strata constitute a sort of transition stage between the rocks of the iron horizon and the black slates. There is no proof of any unconformity either above or below this member, but lithologically it is distinct from the rest. There is a considerable mix-

ture of greenish material, apparently of eruptive origin, either intimately mixed with the silica and fine argillaceous matter or in separate streaks. Even the extremely siliceous cherts which constitute the upper part of this horizon occasionally present a greenish appearance due to intermixture with this basic element. There is sometimes found a layer of dense but soft black argillyte in this zone, which seems to be an indication of the great thickness of similar rocks to be deposited later.

The chert is red, yellow, black, white or green, and in the Thunder Bay region has a thickness of two or three hundred feet. It is not known how thick it is on the central Mesabi. It is not strictly confined to this member of the Taconic, but is occasionally found as low as the basal quartzyte, and above high up in the slates. Its content of silica varies greatly. Now it will have the appearance of pure translucent chalcedony, and again it is mixed with oxide of iron or some carbonate of lime and iron. It frequently possesses a peculiar brecciated appearance, having been thoroughly shattered into angular fragments which are re-cemented by the same amorphous silica.

This angular fracturing or jointing is also visible in the iron ore, even when it is soft enough to excavate with pick and shovel. It is more difficult to account for the large amount of silica in these cherts, which lie above the iron ore horizon, than for that which has enlarged and cemented the grains of the quartzyte below the ore. In the latter case the silica has been removed in carbonated solutions from the ferriferous layers down into the quartzyte and there deposited. How it came to be accumulated in such quantity at the chert horizon is a matter for future study. When the explorer finds this flinty slate formation it is safe to conclude that he is above the ore horizon (that is, above where the ore is, if there is any there) and must go deeper or farther *up* the general slope of the region.

2. Animikie Black Slates.

The upper slaty strata of the last division soon pass into this, which, so far as examined on the central part of the range, consists entirely of several hundred feet of carbonaceous argillytes. Diamond drill records do not show the presence of the interbedded traps which are seen in the same horizon around Gunflint lake and eastward. It is possible that these eruptives may be higher up in these slates and will be discovered by future drilling farther south. These slates have the usual dip of the entire Taconic series on the

Mesabi, viz., from horizontal to 20° to the south or southeast. The dip is locally as high as 45° in some of the ore deposits where they lie close to the green schist.

These slates are supposed to extend southward under the gabbro to the St. Louis river, and then to appear again with a high dip and somewhat distorted stratification. If the St. Louis river slates are Animikie, as supposed, it is quite likely that the lower horizon of iron ore and quartzyte may also come to the surface in the same vicinity, and thus still another iron range may be discovered, still nearer Duluth. It is obvious, however, that with the high dip of the St. Louis slates the ore deposits would soon lead to deep mining and lose the advantages which the Mesabi possesses in lying in flat deposits.

The practical inference to be drawn from black slate outcrops on the Mesabi is that they are always *above* the iron ore horizon, and surface exploration must be pursued in the direction contrary to the dip.

The task of test-pitting through the black slates is almost a hopeless one, for the dip is sufficient to make a depth of several thousand feet in a few miles. In case of diamond drilling, where the property is all within the slate area, the only general advice is to get as near the north side of the property as possible, for if there is any ore under the slate it will be found in a shorter vertical distance there than farther south.

1. Gabbro.

This rock is sometimes called "granite" by explorers. I have heard some of them say that there is granite on both sides of the ore belt in 59–14. But the average explorer knows the difference between granite and gabbro. Granite has a pink color and contains crystalline grains of lavender blue quartz, together with mica or hornblende.

Gabbro is gray—seldom if ever pink, and contains no free quartz. It is almost wholly composed of gray feldspar (labradorite), which has pearly and often striated cleavage planes and is softer than quartz. The hills south of the iron belt in 58–16 are composed of this gabbro, which probably lies above the black slates and underlying iron rocks. The gabbro poured out of the earth's surface like lava and flowed north over the surface of the country, tipping the rocks up on edge and sometimes floating along huge slabs of the Taconic strata several hundred feet long, which are now found standing at various angles surrounded by the cooled gabbro.

From Birch lake eastward for several miles the gabbro flowed so far north as to cover the iron belt completely and we now find it lying on the granite. The effect of the heat of this molten gabbro was to make the iron ore, which already existed in the rocks, hard and magnetic, and this effect seems to have been felt for miles away from the edge of the gabbro.

Other minerals besides iron were changed by the same agency, and even so hard a rock as the quartzyte was so changed that samples of it have recently been designated "altered gabbro" by an eastern petrographer.

There is good reason to believe that the iron ore deposits in their present condition have been formed principally since the gabbro overflow. There was a certain amount of iron in the rocks originally, but this has been greatly augmented and concentrated in more recent times.

Accompanying the gabbro is frequently more or less black magnetic ore, which carries an injurious amount of titanic acid. This black ore occurs in grains in the rock nearly everywhere, and sometimes forms large deposits. It has a dull lustre and is not finely granular like the magnetite of the Taconic strata. It also lacks the evidences of stratification everywhere visible in the quartzyte and associated ores.

The northern and western boundaries of this gabbro sheet are approximately shown on the geological map accompanying Bulletin No. 6 of the geological survey. It will there be seen that there is no trace of this rock known west of range 16, and it is to be expected that the slates will be found immediately under the glacial drift west of the gabbro. The ore also loses its magnetic quality as we approach the Mississippi river, and at Prairie river it is nearly all hematite.

Although parties of explorers have recently gone into the gabbro area on Partridge river, equipped for test-pitting, it is scarcely necessary to say that there is no good reason to expect merchantable iron ore deposits in or under this eruptive flow in any place but along the northern edge, where it covers the ore belt. Farther south it reaches a thickness of hundreds of feet, and the slates below are still hundreds of feet above the ore horizon.

The advice in general is: Keep away from the gabbro. The ore found under it will be magnetic, may be titaniferous and is sure to be mixed with lean siliceous portions which will interfere with cheap mining.

OCCURRENCE OF THE ORE.

In the foregoing pages it has already been indicated how the ore occurs. Among explorers and miners on the range there is great confusion of ideas on this point. It is said to be in veins, and many are still searching for a hanging wall and predicting that the flat portions occurring without one, are what they term "slop-overs." It is quite common to be told that the vein will soon take a high dip to the south and go down at an angle of 60°, more or less, to a great depth. Those who entertain this opinion go still farther and look for the continuation of the "vein" to an indefinite distance across the country in one direction. The proper direction is often rather absurdly ascertained by drawing a line through the locations of two or more mines on the map and extending it across adjacent property for miles. The amount of money already spent in extremely unpromising locations that have been selected in this way would buy several good mines. Others say that the ore is a surface "wash" which has settled in waters of very recent date in troughs or valleys. Still again it is said that the ores are eruptive, and the shiny limonite coating in some cavities is pointed to as unmistakable evidence of fusion and rapid cooling.

The most ancient of ideas is held by some that the ore deposits date from the creation of the world, and those who hold this idea say wisely: "Where it is there it is, and you cannot see any further into the ground than any of us, nor tell us where the ore is likely to occur." It would be extremely rash to deny the truth of the old Cornish saying, but repeated experience has proven that a knowledge of the geology of a region will and does enable us to tell where the ore *probably* exists and where it does not.

The occurrence of the Mesabi ores is not in veins or lodes. No hanging and foot wall proper are to be found. The deposits lie on quartzyte, and for convenience that may be called the foot wall, but it has not the same significance nor does it bear the same relation to the ore body that a true foot wall bears to a true vein. In rare instances the ore will be found with a "capping" of jaspery quartzyte or taconyte varying in thickness from a few inches to thirty feet or more. This will be called a hanging wall, but not properly. Moreover, the course of the ore deposits is not persistent in one direction unless the slope of the ridge on which they lie has a straight trend. The soft ore bodies follow the slopes, and when they change direction the ore deposit usually either comes to an end or changes also. This can be seen at several places, but especially marked at the Mountain Iron mine. The ore first dis-

covered lies in a horse-shoe basin, the sides of which are high and have a steep slope. The ore follows the side of this basin and is discovered in pits which follow the slope around to the northwest, as well as on a subordinate ridge which runs south and southeast for half a mile. There is no principle more universal on the range than this: the presence or absence of an ore body depends on the presence or absence of an elevation, on the slope of which the proper horizon of Taconic strata occurs. This idea will be further explained in discussing the origin of the ore.

The ore deposits are not likely to assume a high dip and thus to extend to great depths. On the contrary, as we go south away from the granite and green schist ridges, the entire formation flattens down and the dip is hardly perceptible. This fact is not indicative of the existence of soft ore deposits under the slates at great distances south from the iron belt, as at present defined.

The ideas of surface "wash" and eruptive flows are also necessarily discarded. The existence of oceanic stratification and the frequent transition from soft ore into the rock strata of the ancient Taconic are alone sufficient to disprove both of these ideas. Moreover, there is no trace of the chemical action which would have taken place if the ores were eruptions, nor does the physical character of the ore harmonize with this idea. The deposition of limonite in shiny coatings in crevices and elsewhere, is by the action of aqueous solutions, and instead of being an indication of heat is just the reverse.

Ore Deposits Occur in Beds.

The Mesabi ore deposits are in regular *beds*. They constitute part of the Taconic strata and are still in almost their original position. They are part of the horizon which lies next above the basal quartzyte. They grade into the rocks of this horizon in all directions laterally, and occasionally both above and below. As a rule, however, the ore lies directly on the softened and disintegrated basal quartzyte which does not contain much iron oxide. The bedding planes of the original strata are perfectly preserved in the ore, as are the joints and even the differences in texture of the various layers of jasper, chert, coarse and fine taconyte and slate.

The ore deposits thus far discovered on the Mesabi, with few exceptions, lie just below the glacial till, which varies in depth from a few inches to one hundred feet. The ore body has a depth equally as great, and usually is wedge-shaped with the narrow end

or side lying toward the top of the slope and the thickest portion farther down. There may be occasionally a knoll or ridge of jaspery quartzyte lying above the surface plane of the slope. In this case the ore generally passes under the knoll, which thus forms a capping; but occasionally this hard knoll or ridge extends downward unaltered to the basal quartzyte and constitutes a "horse" in the ore body. These "horses" are called "dykes" by some explorers. They are not true dykes, however, but parts of the general formation which do not cut through the quartzyte below the ore, as eruptive dykes would.

True dykes are not common along the range, and their absence constitutes one of the chief points of difference between the Mesabi and the Penokee-Gogebic. The accumulation of the Mesabi ores cannot be due in any way to dykes, for there are none associated with the ore, and no ore where dykes are found. This fact indicates that perhaps the ore deposits on the Penokee-Gogebic, instead of being produced through the agency of the dykes in forming troughs in which the ore was deposited, have been formed *in spite* of the dykes and would have been much deeper and more extensive had it not been for them. From what can be seen on the Mesabi, dykes and even troughs are unnecessary features, the ore being due to a replacement and concentration process which has proceeded on all uninterrupted slopes of sufficient pitch where the proper rocks exist for such a change. This operation or process of replacement, moreover, extended as far down the slope as the local conditions have permitted since the rocks were elevated to their present position. If the slope was a long one, and in the shape of a large basin, the ore deposit is large. If it was narrow or interrupted by numerous gorges or ridges, the ore is apt to be limited in quantity and of poorer quality. Where there was an opportunity for the greatest freedom of drainage and the most extensive percolation of solutions through the rocks for a considerable thickness, and over a considerable area, there are found the purest and largest accumulations of ore.

It is quite possible that there may be in places two or more parallel lenses of ore separated by ridges of unaltered taconyte. This might easily occur where the taconyte horizon is uncovered over a considerable area and where the surface consists of an undulating succession of ridges with gradual slopes. The usual dip of the Taconic rocks on the Mesabi is so slight that it does not always exceed the general slope of the surface of the country south of the Giant's range. For this reason there may occasionally be a succession of elevations, on the sides of which are ore deposits; and

since the elevated portions of these ridges are usually magnetitic and the ore bodies are not, a dip needle may be used to advantage in locating the ore. Fig. 2 illustrates this idea.

The nature of the lateral and lower boundaries of the ore deposits will be more or less a matter of speculation until some are mined out. The extensive developments and the large production of ore already arranged for, promise interesting revelations within the next two or three years. At the present time, however, some idea of the appearance of the open pits, when the ore has been mined out, can be gained from a consideration of its mode of occurrence, as already known.

The upper edge is generally thin and rather the poorest ore. If this part of the ore is stripped and taken out it will leave the basal quartzyte exposed, dipping south at an angle of 10° to 40°. The lower side of the ore bed is more or less mixed with sand from this quartzyte. Hence the bottom of the open pits will be an almost plane surface dipping as the quartzyte dips, and at a short distance resembling soft ore more than quartzyte. The ore will gradually deteriorate below a certain depth in all pits and in an excavation until it becomes too poor to be mined.

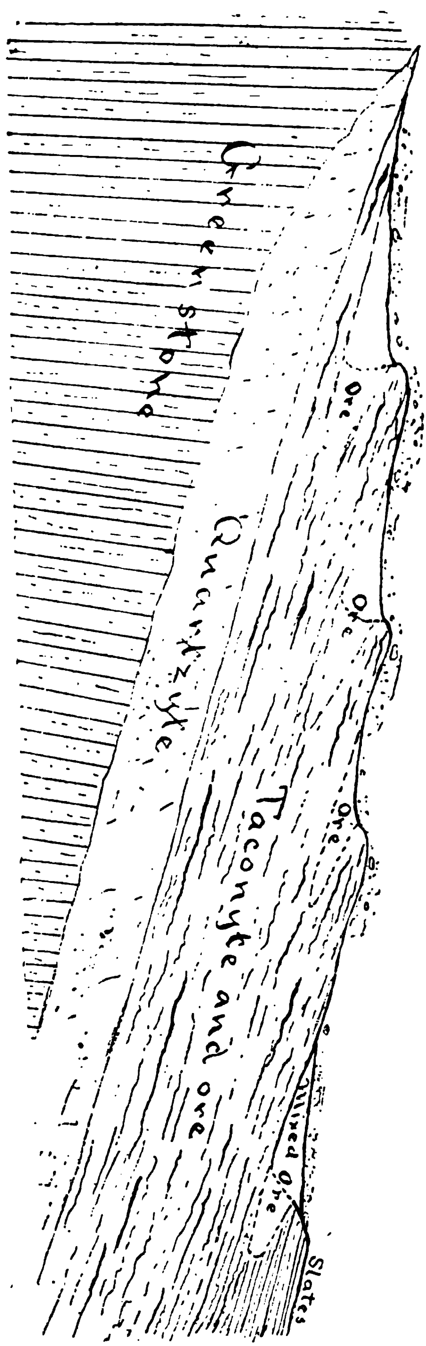


Fig. 2. Possible method of occurrence of parallel lenses of ore.

The sides of the ore bodies will present rather abrupt transitions into the jaspery quartzyte of the iron ore and taconyte horizon. It is not to be supposed that the limits of the soft ore will be marked by a wall or definite boundary plane on any side or at the lowest edge. It is rather to be believed that the ore extends into the rocks in sheets of variable thickness, and that when followed up and mined out, the lower edge of the remaining open pit will have a very ragged appearance something like the following, figure 3.

The ore on the lower, thicker edge may also be expected to deteriorate and become more like paint rock and earthy than the lower strata, which are mixed with sand. The capping or hard ridges already mentioned may present some interesting examples of the process of the replacement of silica by oxide of iron, which can be easily examined and studied when the surrounding ore is removed.

There are other interesting phenomena which can only be explained fully when the ore in their vicinity is removed. There appears to be a gorge on the Lone Jack and Missabe Mountain properties, excavated to the depth of sixty feet in the soft ore by some preglacial stream and subsequently filled with rounded, water-worn pebbles of hard ore. Test-pits on each side of this gorge filled with ore-gravel encounter fine, soft hematite just below the glacial drift, which does not here exceed twenty feet in depth. At the bottom of this ore gravel is a stratified layer or series of layers of white kaolin, more or less stained and mingled with fine red iron ore. This layer varies from a few inches to twelve feet in thickness and its true nature has not been ascertained. Below it is found the same blue hematite which occurs in the test-pits on both sides of the gorge sixty feet nearer the surface.

There are also gorges apparently scraped out by solid ice and filled by sand and gravel. On the Berringer forty, sec. 4, 58-16, a test-pit seventy-two feet deep has been sunk at the edge of one of these gorges. The east half of the pit passes down through soft blue hematite from the depth of forty-eight to seventy-two feet, while the west half of the pit is sand and gravel for the same distance. The wall of the ore is nearly perpendicular and seems to have been planed off. A short distance farther west there is a test-pit nearly one hundred feet deep, which did not strike anything but glacial till. These facts are an indication that the soft ore was essentially in its present condition at the time of the last glacial epoch.

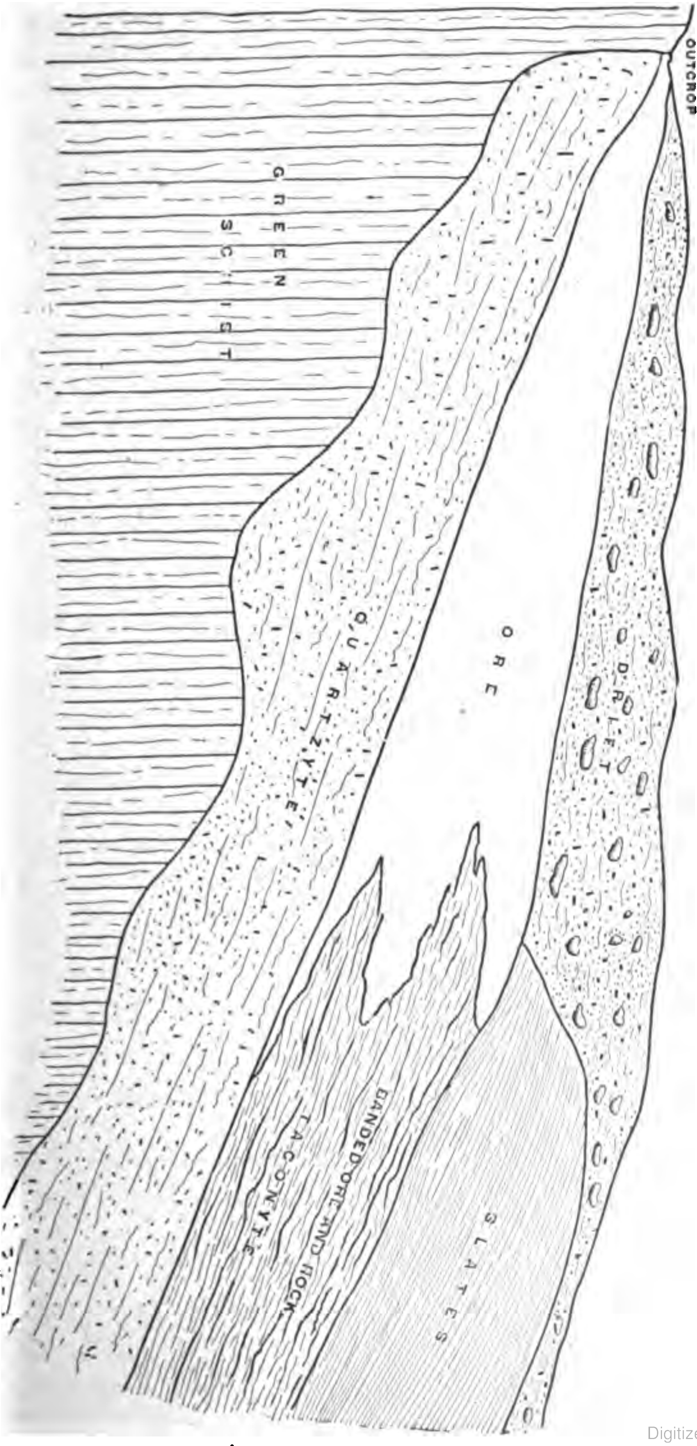


Fig. 3.

GENERAL SECTION AT BIWABIK, SHOWING RELATION OF ORE TO SURROUNDING ROCKS.

Am. Bank Note Co. N.Y.

VARIETIES OF MESABI IRON ORE.

Magnetite.

The ore of the eastern portion of the Mesabi probably owes its magnetic properties to the heat of the gabbro overflow upon the hematites which were deposited in the rocks at the time of their formation in the oceanic waters.

Where this ore is associated with the lower beds of the Taconic it is rather coarsely granular and shiny. The ore which occurs higher up in the horizon is fine grained and compact, having a high specific gravity. Individual samples of this ore show a high percentage of iron and a low content of phosphorus and sulphur. Unfortunately it seldom occurs in beds of sufficient depth to render it valuable without concentration.

It is noticeable that there is a small percentage of magnetic grains in the blue-black, soft, granular hematite of the central portion of the range. A magnet will pick out grains from a handful of this ore from almost any test-pit in which it occurs. Its presence adds somewhat to the percentage of iron in the ore and does not produce any deleterious effect.

Small streaks of black, shiny, crumbling grains were noticed first in the test-pits on the Cincinnati property. They were at once seen to be magnetite, but their occurrence at the depth of sixty feet in solid strata of limonite and hematite was a surprise. The only well known means of producing magnetism in oxide of iron is by a considerable degree of heat. It is evident that it would be impossible to apply heat to a particular streak a couple of inches thick in the depths of such a deposit as that without also heating adjacent strata. Had the heat come from above all that portion of the deposit lying above this particular layer would also be affected by it. Had it been heated in some way from below there would be no hydrated ore left below it.

There are three possible hypotheses:

1. There may be some way to render ores magnetic aside from heating them.

2. This streak may have been heated and magnetized after deposition in its present position before the adjacent strata had their present chemical composition.

3. The ore may have been deposited here as magnetite originally.

In the Tenth Annual Report of the U. S. Geological Survey Prof. Van Hise has advanced the idea of the formation of magnetites by chemical processes during the oxidation and concentration

of iron carbonates. He supposes that in the presence of an insufficient amount of oxygen, siderite may have been altered directly into magnetite. As a proof of this he mentions the fact that some of the magnetite is pseudo-morphous after siderite, and also that the hematite and magnetite are intimately mingled in the rocks of the Penokee-Gogebic range. He even states that it is exceedingly probable that all the magnetite is of secondary origin by chemical alteration of siderite at a low temperature.

In the case of the Mesabi magnetites we may admit that a portion of the magnetic grains may have been produced in this way. It is, however, not admitted that it is wholly due to such action. There are abundant evidences that much of this iron ore is an original constituent of the rocks, as siderite, magnetite, or sesquioxide of iron, probably the latter. The effect of a gabbro overflow would certainly be to render this original ore magnetic, if it were not already so, and less liable to chemical decomposition than the hematite and limonite. The magnetic oxide of iron is its most stable natural compound. It is often found unchanged by atmospheric agencies in exposed situations where other minerals have been deeply eroded and considerably decomposed. While the oxidation of magnetite into hematite is possible and has been observed in certain localities, it is not so common as the series of changes from siderite through limonite and hematite to magnetite. The pseudomorphs of magnetite after siderite mentioned above may be hematite pseudomorphs rendered magnetic by heat.

One difficulty in the way of an acceptance of the idea of this method of the formation of magnetite on the Mesabi is the fact that the magnetic strata are found near the surface of the ground where all chemical changes for a great space of time have been accompanied by an abundance of oxygen. Prof. Van Hise supposes that hundreds of feet, perhaps even thousands, of solid rock have been removed by erosion above the present surface on the Penokee-Gogebic range. There is strong evidence that no such depth of erosion has taken place on the Mesabi. The iron ore beds are essentially surface products, and do not occur under any great thickness of rock strata. The principal agent of erosion is glacial action. The freshness of glacial striæ and the drift mantle covering the rocks show that no postglacial erosion has taken place, and it is not likely that preglacial erosion was conducted to such a great depth. Moreover, it is only by the exposure of the very strata now found at and near the surface during all the ages since the gabbro overflow, that such extensive alteration deposits can be accounted for. Hence, unless the presence of some powerful

reducing agent can be proven, the magnetic element of the rocks must be explained in some way which admits the presence of an excess of oxygen. It is not known at present whether the magnetite extends to any depth under the slates southward or not. All the facts we possess indicate that it does not. The heat of the gabbro cannot be supposed to account for the existence of magnetic ore in the rocks twenty miles or more distant. It may be that simple surface weathering of long duration is able to produce magnetic oxide from sesqui-oxide. It cannot be derived from a carbonate, for the resultant of surface alteration of siderite is always a sesqui-oxide. Admitting, then, that further study is necessary to account for the magnetic strata in the rocks between the Mountain Iron mine and the Mississippi river, we must still affirm our belief that the magnetic streaks in the pits of the Cincinnati represent ore that was originally deposited in the rocks as a hydrated sesqui-oxide and was rendered magnetic by the gabbro overflow. These streaks represent all the iron there was in the rocks at that time. The effect of the gabbro eruption was to elevate the Giant's range, and from that time until the present the process of ore deposition in these rocks by the decomposition of carbonates, if any were present, and the replacement of silica by ferric oxides, has been progressing. The result has been the formation of large deposits of pure ore in which the magnetite layers are interbedded with the more recent non-magnetic ores.

The titaniferous magnetites have already been mentioned. They occur in the gabbro, and are valueless at present. Their manner of occurrence and chemical composition are described fully in Bulletin No. 6, Minn. Geol. Surv.

Gœthite.

This ore is the first to be found below the glacial drift in many test pits on the Hale, Kanawha, Cincinnati, Canton and Biwabik. It is soft, homogeneous yellow ore and occurs in layers several (six to twenty) feet in thickness. It was at first called limonite, but its high percentage of iron, as revealed by several analyses, together with the large amount of combined water showed that it is gœthite. As a rule it is non-bessemer. It is called "yellow ochre" by the miners and is frequently thrown out as poor ore. Its composition when absolutely pure is sesqui-oxide of iron 89.9, water 10.1, metallic iron 62.9. It occurs in such large quantities on this range that the term "Mesabite" may appropriately be applied to it to distinguish it in the iron trade. The following analyses show its purity:

Berringer yellow ochre, Iron 60.65, Phos. .070.

Canton yellow ochre, Iron 60.65, SiO_2 2.09, Phos. .105, Comb. H_2O 8.04. Free H_2O 9.86.

Canton yellow ochre, Iron 60.75, SiO_2 1.85, Phos. .065, Comb. H_2O 10.05. Free H_2O 12.77.

Canton yellow ochre, Iron 60.90, SiO_2 4.85, Phos. .029. Some analyses indicate 61.5 per cent. of iron.

This ore will perhaps be of more value for the manufacture of mineral paints than for use in the furnace. It can be obtained cheaply and in large quantities.

LIMONITE.

Hard masses and layers of brown hematite are found in many pits on the Mesabi. The ore is inclined to be siliceous and rather high in phosphorus. Many cavities are lined or filled with grape and pipe limonite ore. It seems to occur in portions of the ore bodies where considerable streams of water flow, continually or at certain seasons of the year, through the rocks and ore. Only a small percentum of all the ore in any mine so far discovered has been shown to be of this mineral. It is perhaps the least valuable of any except the titaniferous ores on the range.

HEMATITE.

By far the larger part of Mesabi ores are hematites, as the term is used by mineralogists, *i. e.*, anhydrous sesqui-oxide of iron, whether hard or soft, crystalline, massive or earthy, red, blue, purple, brown, green or black. All varieties and all textures occur on this new range. The variation in appearance is remarkable, but the uniformity of composition is equally so. It is only after considerable experience in the ores of the range, and a careful examination of each variety by a hand-glass that the ore expert can tell which ore is the best and approximate its percentage of superior excellence. To be sure there are high and low grade ores here as on any other range, but samples of ores of at least ten totally different macroscopic characteristics can be selected that will not vary two per cent. in iron content. The process of ore formation here has been a discriminating and selective process, and has progressed regardless of color, hardness or texture.

The best grade of hematite is the blue-black soft ore found at many of the mines. Where this ore is in perfectly crystalline grains which possess little adherence to each other and will not "pack" in one s hand as do the more earthy ores, the percentage of iron reaches almost absolute purity. One sample of thirty feet of this ore from pit No. 15 on the Biwabik, taken by E. P. Jennings, yielded an analysis of 67.90 per cent. iron, 1.8 per cent. silica and

.016 per cent. phosphorus. Such ore as that is not excelled anywhere. It is this exceedingly pure ore that brings up the average of Mesabi ores. Without it there are several properties which would be non-bessemer; with it they are a good bessemer.

The general order of succession of the various kinds of ore is indicated by the plates of sections (Plates I, II, III, IV, V) from the Biwabik, furnished me by Mr. Jno. T. Jones and P. L. Kimberley.

Manganiferous Ores.

Black oxide of manganese is found in hard and soft streaks in the ore of many mines on the range. As yet it has not been found in sufficient quantities to guarantee any considerable production of manganese ore or manganiferous iron ore. It will be strange, however, if some such ore is not produced from the range, since so many indications are met with, and the conditions are so favorable for its accumulation. Moreover, such ore is mined in limited quantity on the Penokee-Gogebic range, which is the undoubted equivalent of the Mesabi.

ORIGIN OF MESABI ORES.

In Bulletin No. 6, on the Iron Ores of Minnesota, the idea was advanced that the bands of ore found interstratified with the Taconic rocks of the Mesabi are due to oceanic precipitation as hydrated sesqui-oxides at the time the sediments were deposited. Subsequent pressure and heat are supposed to have dehydrated the ores and the gabbro outburst to have rendered them magnetic. This idea is still maintained and has been strengthened by recent observations. But it accounts for only one portion of the Mesabi ores. Those original bands of iron were of limited thickness and were interstratified with rock material. The ore deposits recently discovered have none of these rock strata left. They were either never present or have been removed. On page 146 of the report referred to above is also found the following statement:

"We are quite ready at this time to adopt the theory that has been referred to originating with Prof. Edward Hitchcock, and more recently adopted by Prof. J. D. Dana and Prof. R. D. Irving, that these carbonated beds may be changed, and have been, on a large scale in the Taconic rocks of New England and of the Penokee-Gogebic range, by infiltrating waters, that their alkaline constituent has been carried away and their iron has been redeposited or concentrated in a residual condition as ferric oxides, and that by this concentration large beds of iron ore have been formed. It is

because of this that we state our belief that possibly important beds of limonite or hematite, originating in this way, may yet be found in the Taconic region of Minnesota, the parallel of those that have recently been opened up in northern Wisconsin." This is a partial statement of the theory adopted by the writer for the ore deposits under discussion. From careful personal examination of the work on all parts of the Mesabi during its entire process of development, the idea has become stronger and more firmly fixed in his mind that these deposits are mainly due to chemical alteration and replacement of some mineral by oxide of iron. There is a general harmony of facts and phenomena observed which go to support this idea, and which apparently are not in consonance with any other theory. The usual conditions existent at the different mines on the range, so far as they have been exploited, are the following:

1. There is a deposit of ore situated on some hill-side or in some basin.
2. This ore is regularly stratified.
3. The planes of stratification dipping less than 30° pass from the ore into and through the banded jaspery quartzyte or taconyte horizon in three directions and occasionally on all four sides.
4. The ore strata correspond in texture with the rock strata which appear to be their continuation.
5. Underlying the ore is usually a quartzyte horizon.
6. Just beneath the ore this quartzyte is decomposed into a crumbling sandstone, but it becomes vitreous a few feet below.
7. This quartzyte is impervious and presents an absolute barrier to surface infiltration. This fact is shown (1) by microscopic examination of the vitreous quartzyte, (2) by test-pits sunk into it, (3) by the large amount of surface water in the ore as the boundary between the ore and quartzyte is approached. The ore is porous and permits the water to filter through it. Test-pits are sunk through dry ore to the depth of nearly one hundred feet, where the ore body covers a considerable area, but water in large quantity is invariably encountered a few feet above the quartzyte.

Exceptional occurrences which tend still further to prove the replacement theory are, (1) the existence of deposits of half ferrified rocks with ore in bands and in isolated centers of deposition. In such situations the process of ore production, or natural manufacture, so to speak, can be observed in all stages of progression. (2) The occurrence of knolls of taconyte lying on top of the ore deposits, having been above the course of the chemical percolations, and thus having remained unaltered.

It is a fact confirmed by abundant observation that the iron ore occurs precisely at the taconyte horizon. It lies neither above nor below it, but in it and of it. It is natural that the process of this transformation into ore should be limited by the local environments. If the angle of the slope down which surface waters have flowed be too steep or too flat there is no resultant ore body, if it is moderate the ore deposit may have been produced to a great depth and width. If the basal quartzyte comes to the surface at the upper side of the slope the atmospheric waters appear to have flowed down along the line of separation between the taconyte and quartzyte. In this case it may happen that the process of replacement extended but a short distance above the quartzyte and there may be an unaltered capping of taconyte above the ore. If the hill side and top are covered with the jaspery quartzyte and banded ore formation the infiltrating waters sometimes seem to have worked a change downward into these rocks and there may or may not be an unaltered remnant of the taconyte horizon below, according to the original thickness and the natural facilities for chemical action.

There is even a third case seen on the Chicago property, in which a body of soft ore nine feet thick has been produced in the taconyte formation, and is seen graduating into the hard banded rock on all sides.

The process of replacement is of two or three varieties. Certain strata seem to be more easily ferrified than others, and instances are common where the wavy line of ferruginization is seen encroaching upon the blue or gray unaltered taconyte. This may often be followed in a single hand sample from taconyte to ore, while the stratification, texture and often appearance remain the same. The remarkable part of it is that all the original mineral elements have gone and the result is such pure oxide of iron. There is much silica of a chalcedonic or amorphous nature in the taconyte, and occasionally layers of quartzyte, but all these can be observed in the actual process of replacement by iron ore.

On the Cincinnati property it even appears that some of the basal quartzyte has been replaced by iron oxide. Samples taken from here show a complete transition from quartzyte to iron ore. In some of the intermediate samples the individual grains can be seen in all stages of removal. There are many encased in a shell of hematite, which can be seen increasing in thickness until on breaking the black grain no white silica grain is found. It has all been removed. With a specimen of this sort in hand it is impossible to doubt that here is an instance of the removal of silica and its replacement by sesqui-oxide of iron.

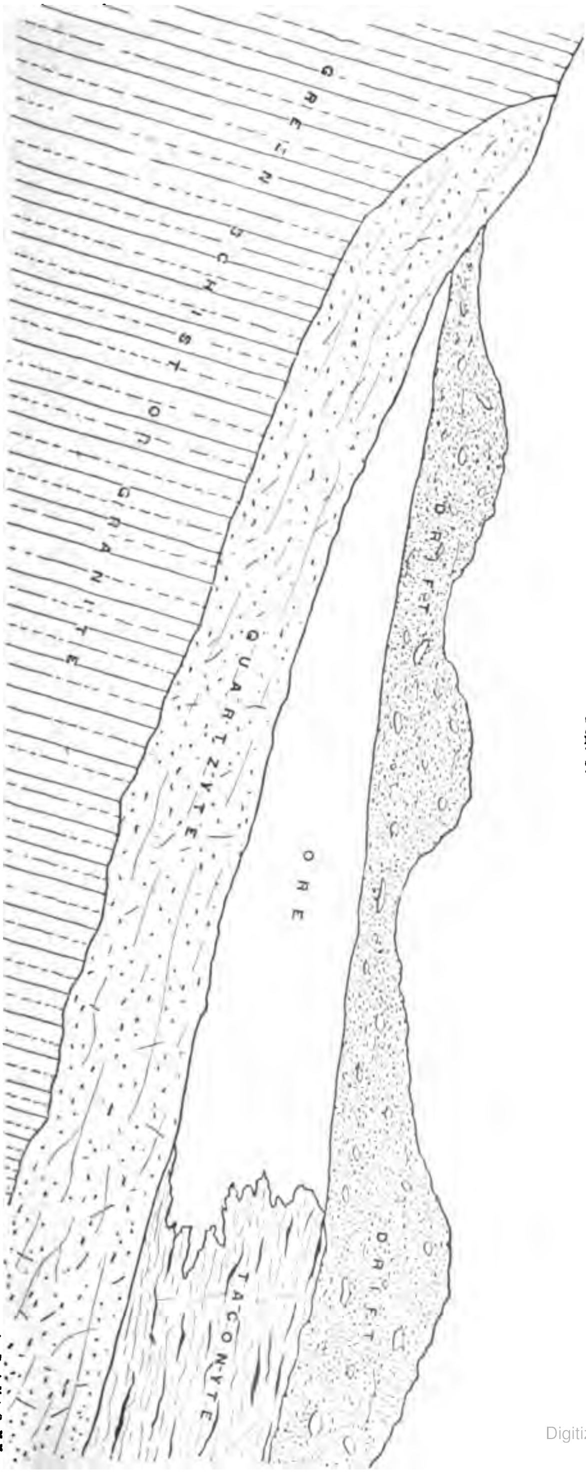
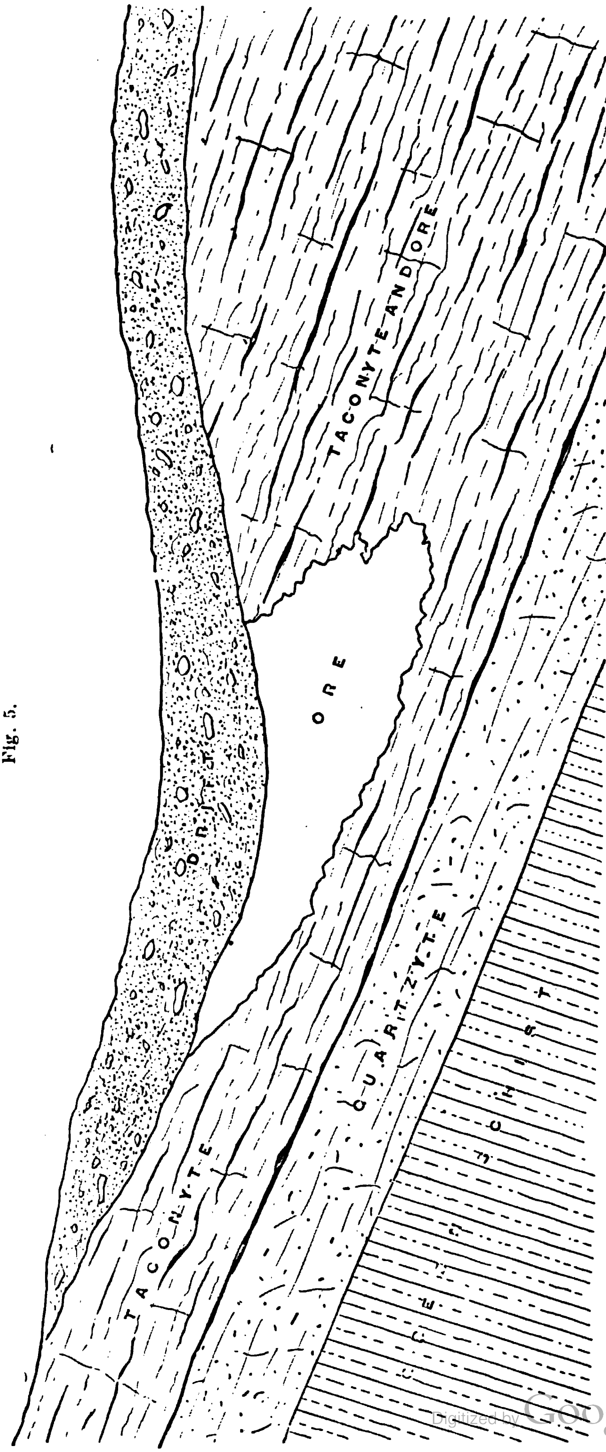


Fig. 4.

USUAL OCCURRENCE OF ORE BELOW DRIFT AND RESTING ON QUARTZYTE

Am. Bank Note Co. N.Y.

Fig. 5.



POSSIBLE METHOD OF OCCURRENCE OF ORE ON TACONYTE

Am. Bank Note Co. N.Y.

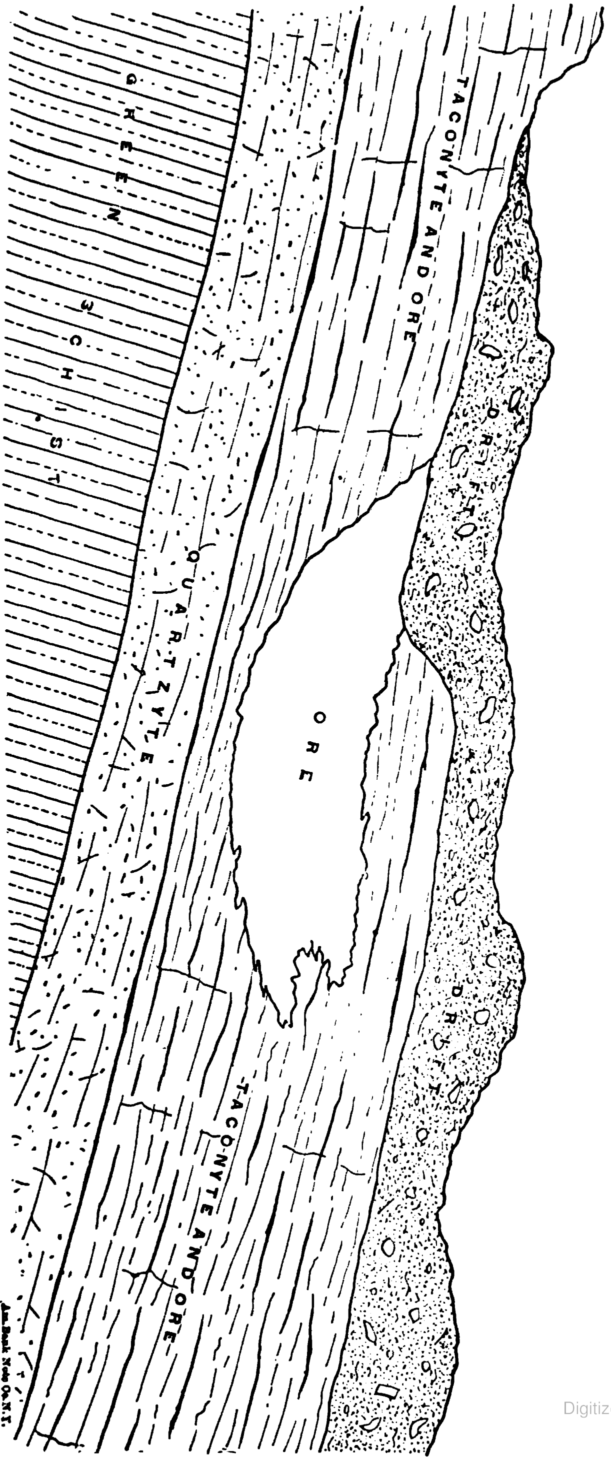


Fig. 6.

POSSIBLE OCCURRENCE OF ORE SURROUNDED BY TACONYTE AND ORE.

Am. Bank Note Co. N.Y.

Still another proof is found in the nature of the transition back again from ore to the taconyte on the lower edge of the deposits.

This has already been referred to under the head of "Mode of Occurrence of the Ore." If this ore be not a replacement product it must continue underneath the rocks belonging higher up in the formation and will ultimately be mined to a great depth. There is no absolute proof that this is not so. On the Biwabik and Cincinnati, however, the ore is seen to degenerate and pass into a low grade ore and then into "paint rock" and finally into the regular banded taconyte horizon on the southern edge.

There have been reports of the discovery of soft ore at great depths under the slates to the south of the present deposits, but these reports are not as yet authenticated. Even if they should be at one or two places in the basins of lakes like the Embarrass it would not weaken the replacement theory. For it is only natural that the effect of a body of water pressing downward through and into a series of soft slates would have some softening, oxidizing and disintegrating effect. The carbon of the graphitic slates would be dissolved and silica removed by it so that replacement deposits might be formed in such a place even at a depth of five hundred feet. It should be mentioned, moreover, that the glacial drift exceeds one hundred feet in depth on the southeast shore of Embarrass lake and may be twice as deep in the lake basin. This would make the actual depth from surface influences very much less and increase the likelihood of an ore deposit.

In searching for an explanation of this process of replacement we are met with many puzzling questions, and it is just as well to admit that more study is necessary for their solution. What started this process? How could so much quartz be removed? What has become of it? Where did all the iron come from? These and many other questions have presented themselves time and again.

It has been advocated that the iron ore of the Gogebic range was originally in the form of a carbonate which in the process of oxidation yielded the necessary solvent for the quartz. We find some traces of carbonates of lime and iron in the Mesabi rocks, but it does not appear in sufficient quantity to permit the assumption that the ore was originally a carbonate. There are not yet discovered any considerable non-oxidized carbonaceous portions of the rocks associated with the ores, except in the more recent slates of the Animikie, which are now found further south. It does seem probable, however, that the solvent for the silica was carbonic acid in aqueous solution, and its early source may have been (1) the

atmosphere, (2) the black slates, which may have covered the ore horizon at one time and have since been eroded. (3) More recently decaying vegetation must have supplied a considerable amount.

The amount of carbonic acid gas in the atmosphere at the beginning of Silurian time is stated by different writers to have been far greater than at present. It is supposed that the Carboniferous was a period of dense atmospheres and warm temperatures. Dana states that in Archæan time the effects of carbonic acid must have been much greater than now owing to its much larger proportion in the atmosphere, and that it has gradually diminished in quantity up to the present time. He states after Hunt that the excessive proportion of carbonic acid in the atmosphere was the most efficient of all agents in rock destruction. Manual of Geology, p. 156. T. S. Hunt states that "all carbonates of lime, whether directly formed by the decay of calcareous silicates or indirectly through the intervention of carbonates of manganese, or alkalies, derive their carbonic dioxide from the atmosphere. The same must be said for the dolomites, magnesites and siderites, * * * the earth contains fixed in the form of carbonates, a quantity of carbonic dioxide, which if liberated in a gaseous form, would be equal in weight to one hundred if not two hundred atmospheres like the present." Min. Phys., pp. 37-38. Here, then, may be the explanation of the removal of silica in such large quantity. If the rocks which produced the present iron ore deposits have been uplifted and exposed to surface action since primordial time, the carbonic dioxide used in the removal of silica must have been derived, at least in part, from the atmosphere. This process would have been carried on to a considerable depth, and may have produced an appreciable effect, even below several hundred feet of sediments which may have since been eroded.

But if these iron bearing strata were ever covered by the slates which belong above them, we can find an abundance of carbon in these very black slates, and though it is not now in the form of carbonates, yet the action of surface waters would be such as to extract sufficient to make a carbonic acid solution powerful enough to take iron and silica into solution. Moreover, Hunt says "the removal of silica in soluble form does not depend on the intervention of alkalies." And the carbon in the graphitic Animikie slates may have been at earlier times in some form more readily taken into solution. Having thus hinted at an answer to the first two or three questions which naturally arise in this connection, let us consider another one.

What has become of all the silica supposed to have been removed from the present location of the iron ores?

The answer to this is short. It was re-deposited in the rocks lying below and farther down the slope. (1) There is need of a source for an enormous amount of silica which has been added to the grains of quartz in the quartzyte, making it vitreous and filling all interstitial spaces. (2) There are considerable amounts of chalcedonic and flinty silica found associated with the quartzyte, and in the other rocks associated with the ores. This silica may be largely from a different source, but it may be partially derived from the leaching of the ore beds. (3) There are deposits of silica in all the cracks and fissures of the slates which lie at a lower elevation but stratigraphically above the ore horizon. Test-pits, for instance, on the Rouchleau, south of the Biwabik, encountered black slates and found no ore. These slates had been more or less jointed and the joints were filled by a bluish silica, sometimes mammillated, sometimes drusy. It is apparent to an observer that the most natural source for this silica is in the ore deposits fartner up the hill to the north. Future researches will throw more light on this subject, and will perhaps show other ways in which the removed silica has been re-deposited.

As for the source of the iron, it is believed to have been largely the result of oceanic deposition, both chemical and mechanical, and to have been simply concentrated in its present situations.

There was also a removal of iron in solution. It was brought down to supply the places whence the silica was taken. These solutions followed the natural drainage courses. Elevation of the strata produced general jointing. The rocks on top of an elevated knoll were cracked full of joints, and the waters had free and abundant opportunity to percolate downward even in some places where the slope was not sufficient to accomplish it otherwise. The iron now being mined may formerly have been disseminated through rocks now completely removed by erosion.

QUALITY OF MESABI IRON ORE.

For some unknown reason the opinion prevailed for several months after the discovery of many of the best mines on the range, that the ore was of inferior quality. This may have been due to false reports purposely circulated by those who had no desire to see a new range discovered and exploited in competition with the mines in which they were interested; or it may have been due to honest but incorrect sampling. Each addition to the family of lake Superior

iron ranges is received more unkindly by the older brothers and sisters. Dame Nature seems to have bestowed her best favors on her youngest children. The Vermilion, Gogebic and Mesabi ranges have each in turn revealed newer and greater riches. It was with extreme reluctance that the proprietors of mines in other districts recognized the importance of the Mesabi. Indeed they have not yet done so, nor will they until next year, when the ore finds its way to the markets and furnaces of the East.

It is true that the first test-pits were sunk on the thin upper edge of the ore, and the upper strata are not so rich as those lower and farther down the slope on which the deposits lie. The analyses first obtained, however, were sufficient to convince an unprejudiced person of the importance of the new district. The average of a large number of samples taken in January and February, 1892, indicated that the ore would yield about sixty per cent. metallic iron and that seventy-five per cent. of it would be within the bessemer limit as to phosphorus. Since then the test-pits have been increased in depth and number and the quality of the ore taken out has improved, as will be seen from the analyses which follow. There has been still further improvement since these samples were taken.

Method of Sampling.

The most reliable samples are "pit samples." The usual method of obtaining them is by standing in a barrel or bucket, pick in hand, and while being lowered from the top to dig out a groove in the side of the pit from top to bottom, letting the ore fall into the barrel. Upon reaching the top the ore is broken into small fragments if it is not already fine, and carefully mixed and quartered down to a sample of eight or ten pounds. Taken in this way the samples should fairly represent the ore that will be shipped from that pit. All the hard layers must be grooved out as deeply as the soft ones, for the percentage of iron may vary; and, of course, sand streaks must be included, for they cannot be eliminated in mining. It is remarked by all new-comers that the ore has a sandy appearance and feel. There are occasional small streaks of sand in it, and near the bottom small grains of white silica are common, and can be seen by a hand glass. Analyses are surprising to these ore experts as revealing but a small per cent. of silica. The sandy feel is due to the nature of the ore, which is largely made up of crystalline grains of hematite.

The habit, quite general on the range, of dumping successive bucket-fulls of ore on a circular stockpile and spreading it around evenly renders dump samples rather unreliable. It is evident that

the last ore mined is on the top of the dump, and as it is not feasible to dig to the center of a dump twenty or thirty feet across, the sample taken will represent but a part of the ore penetrated by the pit. To be sure the sample is as likely to vary one way as the other, but it is not satisfactory unless the pit is quite uniform or the ore has been divided as it was taken out.

The following table of analyses does not do full justice to all of the mines represented. The Berringer, Canton, Lake Superior, Lone Jack and New England have already made developments showing a higher grade of ore, and there is no doubt that some of the others will improve with further development.

Analyses of Mesabi Iron Ores.

BERRINGER MINE.

PIT NUMBER.	SAMPLER.	Iron.	Silica.	Phos.	Mang.	Comb. Water.	Free Water.
0.	E. P. Jennings	57.50	10.33	.108			
4. First 10 ft.	J. A. Crowell	60.70		.069			
4.	J. A. Crowell	62.15		.049			
4. Dump	J. A. Crowell	63.10		.032			
4.	W. J. Rattle	61.90		.051			
?. Ochre	J. A. Crowell	60.95		.070			
?. 60 ft. ore	E. P. Jennings	59.20	4.41	.111			
4. 35 ft. ore	E. P. Jennings	62.60	8.58	.049			
Average		60.97	6.05	.067			

BIWABIK MINE.

PIT NUMBER.	SAMPLER.	Iron.	Silica.	Phos.	Mang.	Comb. Water.	Free Water.
1. Dump	J. T. Jones	55.55	9.77	.107		6.64	12.21
1. 22 ft. ore	J. T. Jones	58.25	4.49	.112		7.05	6.63
2.	D. H. Bacon	60.32	5.07	.121	.37		5.37
9.	P. L. Kimberley	61.95	2.92	.090		6.48	7.50
11.	J. T. Jones	61.05	4.42	.075		5.35	2.93
11.	D. H. Bacon	61.44	3.59	.076	.17		6.33
11.	W. J. Rattle	61.50	4.01	.075	.957		
11.	E. P. Jennings	59.30	8.57	.075			
11.	H. V. Winchell	61.58	4.07	.058	.16	6.48	5.59
11. 58 ft. ore	J. T. Jones	61.95	2.92	.092			2.50
13.	P. L. Kimberley	55.25	7.36	.039		6.25	11.85
15. Blue ore	J. T. Jones	66.50	1.57	.015	.21		
15. Upper 6 ft.	J. T. Jones	67.90	1.23	.010			
15. Lower 10 ft.	J. T. Jones	66.60	2.04	.012			
15. Whole pit	H. V. Winchell	64.30	3.20	.038	.349		
15. Blue ore	W. J. Rattle	66.70	1.84	.022	.442		
15. Brown ore	W. J. Rattle	62.90	3.35	.047	.587		
15. Red-brown	W. J. Rattle	62.90	2.59	.045	.331		
15. Selected	H. V. Winchell	68.15	1.025	.011			
15. 30 ft. blue	E. P. Jennings	67.90	1.80	.016			
15. *Drift	E. P. Jennings	64.40	4.36	.027			
15. *Drift	J. T. Jones	65.80		.034			
15. Brown-blue	E. P. Jennings	65.90	2.70	.042			
15.	J. T. Jones	67.50		.010			
15. First 20 ft.	J. A. Crowell	61.85		.037			
15. Last 16 ft.	J. A. Crowell	63.20		.032			
15. 30 ft. blue	E. P. Jennings	64.50		.018			
15. First 10 ft. drift	J. A. Crowell	67.25	1.88	.010			
15. 0-20 ft. drift	J. A. Crowell	67.00		.020			
15. 20-30 ft. drift	J. A. Crowell	65.80		.034			
15. 30-40 ft. drift	J. A. Crowell	66.20		.039			
15. 40-50 ft. drift	J. A. Crowell	66.00		.038			
15. 70-80 ft. drift	J. A. Crowell	66.50		.015			
15. 80-90 ft. drift	J. A. Crowell	66.60		.012			

*From 150 foot drift at depth of sixty-five feet.

BIWABIK MINE.—*Continued.*

PIT NUMBER.	SAMPLER.	Iron.	Silica.	Phos.	Mang.	Comb. Water.	Free Water.
15. 90-100 ft. drift	J. A. Crowell	66 00		.015			
15. 100-110 ft. drift	J. A. Crowell	66 20		.013			
15. Dump	H. M. Curry	65 850	2.450	.022	.160	2.2	
17.	J T Jones	63.25		.056			
17.	J. T. Jones	58.60		.069			
17. Brown	E. P. Jennings	63.40	5.04	.033			
17. 97-107 ft	J. T. Jones	64 15		.023			
17. 67-77 ft	J. T. Jones	64 00		.026			
17.	J. T. Jones	63 25		.056			
17. 72 ft. ore	J. T. Jones	65.34		.035			
17. 63 ft. ore	W. H. Smith	67.20	1.27	.017	.130	2 06	
19. 30 ft. ore, 56 ft. deep	H. M. Curry	64 20	2.070	.054	.110	5.00	
19 18 ft hard ore and soft ore 86½ ft. down	H. M. Curry	66.25	1.63	.034	.250	2.70	
19. 2½ ft. brown ore at bottom	H. M. Curry	64.75	1.450	.072	.290	5.67	
20.	E. P. Jennings	62.60	5.83	.064			
20. First 15 ft	J. T. Jones	62.40		.065			
20. 15-25 ft.	J. T. Jones	62.40		.068			
21. First 15 ft.	J. T. Jones	50 85		.047			
21. 15-25 ft.	J. T. Jones	62.50		.063			
21.	E. P. Jennings	57.40	11.04	.093			
23. Blue ore 7 ft. from bottom	H. M. Curry	67.35	1.85	.015	.130	1.10	
24. Bottom ore	H. M. Curry	64.050	1 71	.027	.240	4.88	
25. Dump ore, just under surface	H. M Curry	63.45	2.85	.028	.370	4 6	
26. 37 ft. at base	H. M. Curry	65.50	1.73	.049	.060	3.3	
26. 5 ft. at bottom	H. M. Curry	66 40	1 63	.043	.080	2.4	
26. Blue ore at base	H. M. Curry	63 25	2.75	.042	.300	3.1	
Average		63 70	3.46	.0455	.284	3.01	6·76

CANTON MINE.

3.	D. H. Bacon	57 22	7.47	.063			9.50
... North pit	D. H. Bacon	63.13	2.29	.030			7.65
?. Yellow ochre	J. T. Jones	60.65	2.09	.105		8 04	9.86
?. 20 ft. sur., 45 ft. ore	J. T. Jones	59 15	4.31	.048		9 21	10.22
?. Yellow ochre	E. P. Jennings	60.90	4.85	.020		10.05	
Average		60.21	4.20	.059		9.10	9.307

CINCINNATI MINE.

1. "Poor ore"	P. L. Kimberley	54.85	15.06	.026		2.35	8.09
2.	J. T. Jones	59.95	8 35	.032		3.16	8.44
2.	W. J. Rattle	60 10	8 60	.040	.475		
3.	J. T. Jones	61.65	5.39	.031		3.24	4.80
3.	W. J. Rattle	59.80	8 40	.040	.437		
3.	H V. Winchell	59.24	10.25	.046			4.01
4.	E. P. Jennings	62.50	4 89	.087			
5 [Biwabik]	P. L. Kimberley	63.00	3.84	.029		5.03	3.16
5. [Biwabik]	W. J. Rattle	61.50	4 83	.039	1.98		
5. [Biwabik]	E P. Jennings	63.50	5.37	.030			
5. [Biwabik] dump.	H. V. Winchell	59.00	7.65	.050			
7.	W. J. Rattle	57.80		.038			
8.	E. P. Jennings	54 50	14.13	.028			
8.	J T. Jones	60.70	8.10	.034		2.85	10.96
8. Dump	J. T. Jones	58.50	8.90	.045		5.39	7.55
8.	W. J. Rattle	51.90	16.00	.040	.515		
9.	E P. Jennings	54.40	14.13	.028			
9.	W. J. Rattle	54.50	9.08	.078	.460		
10.	E. P. Jennings	55.70	9.06	.112			
10.	W. J. Rattle	55.10	8.68	.110	.810		
10. Dump	H. V. Winchell	55 75	7.38	.078			
12.	E. P. Jennings	56.80	6.00	.063			
... Second from north	E. P. Jennings	57.20	12.88	.034			
Average		58.30	8.95	.0498	.791	3.67	6.71

GREAT WESTERN MINE.

PIT NUMBER.	SAMPLER.	Iron.	Silica.	Phos.	Mang.	Comb. Water.	Free Water.
4.	J. A. Nichols	65.02		.024			
5.	J. A. Nichols	63.71		.020			
Average		64.36		.022			

HALE MINE.

1.	D. H. Bacon	61.16	2.89	.063	.40		7.05
2.	W. J. Rattle	61.48	3.60	.088	1.20		
3.	W. J. Rattle	61.10	4.92	.067	.849		
4.	W. J. Rattle	62.10	2.92	.075	1.29		
5.	W. J. Rattle	57.60	5.95	.077	1.657		
Average		60.67	4.05	.074	1.079		7.05

KANAWHA MINE.

2.	J. T. Jones	64.45	3.32	.050		5.29	11.76
2.	W. J. Rattle	60.65	4 90	.051	.644		
3.	W. J. Rattle	59.60	6.40	.081	.754		
4.	W. J. Rattle	59.10	7.48	.084	.405		
Average		60.95	5.52	.066	.600	5.29	11.76

LONE JACK MINE.

1.	D. T. Adams	59.415	7.55		.251	3.05	
1. Bottom	H. M. Curry	58.565	6 75		.348	3.15	
1.	E. P. Jennings	55.00	9.29	.096			
2.	D. T. Adams	60.806	4.78		.775	2.05	
2. Bottom ore, dump	H. M Curry	60.225	3.716	.089	.540	2.08	
Average		58.402	6.417	.092	.478	2.55	

McKINLEY MINE.

1.	D. H. Bacon	60.32	10.72	.024	.770		1 89
2.	D. H. Bacon	61.48	9.27	.022			1.64
?.	J. M. Clifford	65.60	4.10	.017			
Average		62.46	8.03	.021	.770		1.76

MISSABE MOUNTAIN MINE.

1.	J. T. Jones	63.30	3.617	.051		1.85	
1. Upper 10 ft	H. M. Curry	56 80	7.20	.041	.580	3.30	
1. [?]	J. T. Jones	62.40	4 80	.026	.270	1.78	9.80
1. [?]	J. T. Jones	62 89	3.38	.061		2.92	
1.	C. F. Howe	65.21	3.83	.037		2.26	
1. 45 ft. ore	H. V. Winchell	64.03	3.094	.053	.337	1.75	6.70
3.	H. M. Curry	60 05	4.65	.075	1.090	3.40	
3. Dump	W. H. Smith	62.33	5.53	.027	.840	1.15	
4. Top of dump	H. M. Curry	61.304	5 40		.508	5.10	
4. Dump	H. V. Winchell	60 90	3.14	.080			
5. Dump	H. M. Curry	56.817	11.967	.050	.180	1.76	
?.	E. P. Jennings	64.30	4.36	.077			
?.	E. P. Jennings	62.50	4.89	.087			
Average		61.73	5.066	.055	.542	2.52	8.25

MOUNTAIN IRON MINE.

PIT NUMBER.	SAMPLER.	Iron.	Silica.	Phos.	Mang.	Comb. Water.	Free Water.
1. [Old number]	D. H. Bacon	62.43	5.70	.047			4.15
2. [Old number]	D. H. Bacon	59.12	11.48	.048			2.74
1. [New number]	— Joyce	65.60		.052			
2. [New number]	W. H. Smith	62.250	6.820	.038	.116	2.60	
1.	Geo. Sutherland	63.98		.029			
2. 18 ft. ore	H. M. Curry	57.68	13.35	.054	.130	2.20	
2.	Geo. Sutherland	66.19		.068			
3. 14 ft. ore	W. H. Smith	64.93	3.70	.057	.238	1.88	
2.	L. B. Miller	61.90	5.82	.048			
3.	H. M. Curry	65.14	4.11	.048			
3.	Geo Sutherland	65 14		.048			
4.	H. M. Curry	65.55	4.14	.037			
4.	L. B. Miller	65.00	3.51	.033			
4. 23 ft. ore	H. M. Curry	64.242	4.98	.035	.232	2.80	
6.	Geo. Sutherland	66.52		.031			
4. 18 ft. ore	W. H. Smith	59.81	8.66	.057	.155	3.99	
7.	L. B. Miller	65.30	3.08	.053			
?. Lammers, Chem.	?	63.68	6.77	.041			
8.	L. B. Miller	65.30	3.07	.054			
?. Lammers, Chem.	?	62.52	2.74	.031			
9.	L. B. Miller	66.00	2 49	.046			
?. Lammers, Chem.	?	62.65	5.20	.056			
Average		63.22	5.64	.050	.155	2.674	3.495

NEW ENGLAND MINE.

PIT NUMBER.	SAMPLER.	Iron.	Silica.	Phos.	Mang.	Comb. Water.	Free Water.
1. 26 ft. ore	E. P. Jennings	58.30	5.99	.084			
2.	E. P. Jennings	62.60	5.64	.037			
3. 20 ft. ore	E. P. Jennings	61.80	6.44	.029			
Average		60.90	6.02	.050			

OHIO MINE.

PIT NUMBER.	SAMPLER.	Iron.	Silica.	Phos.	Mang.	Comb. Water.	Free Water.
3.	E. P. Jennings	63.20	5.07	.032			
3. Pit, last 20 ft.	J. T. Jones	64.53	4.20	.047	.414	1.91	
4. 26 ft. ore	E. P. Jennings	64.45	3.08	.037			
3. Dump, last 20 ft.	J. T. Jones	61.25	8.783	.020	.450	1.48	
Average		63.16	5.34	.036	.432	1.695	
Average of averages		61.46	5.92	.0528	.667	4.063	6.886

COMPARISON WITH OTHER ORES.

Until there shall have been a large consumption of the Mesabi ores it will be impossible to tell exactly how they compare in all respects with the ore of other districts. There are high and low grades of ore on all ranges, and the average tonnage purity of an entire range has never been determined. By this is meant the average quality of the ore taking into consideration the number of tons of each grade mined. Some idea of the comparative excellence of Mesabi ores, however, can be gained by a consideration of the analyses already given and the actual results obtained in other instances.

The output of the Minnesota Iron Company from the Vermilion range in 1891 is classified in the following table. This ore is well-known as some of the finest hard hematite obtainable, and yet only forty-seven per cent. of the product was bessemer.

TABLE SHOWING PRODUCT OF THE MINNESOTA IRON COMPANY IN 1891.

SHAFT.	Vermilion.	Soudan.	Red Lake.	Minnesota.	Nipigon.	Total.
No. 1	2,813	24,379	6,581	14,615	....	48,388
No. 3	298	10,939	1,065	46,382	346	59,330
Alaska	....	....	14,243	....	....	14,243
No. 5*	....	21,779	6,655	159,836	3,983	192,253
No. 7	....	46,174	6,324	5,068	....	57,566
No. 8	92,464	591	10,073	....	....	103,128
No. 9	154	5,683	2,423	11,126	425	19,811
No. 10	....	15,341	742	....	....	16,083
No. 10 Scram	....	1,177	82	....	....	1,259
No. 17	....	377	834	676	....	1,887
No. 13	....	2,319	913	....	....	3,232
No. 12	....	21	91	....	....	112
No. 19	....	....	278	....	....	278
Total	95,729	128,780	50,304	237,703	5,054	517,570

*Includes Montana, Butte, Armstrong and No. 6 Shaft.

Pickands, Mather and Co., the Cleveland agents for these grades of ore, give the following average analyses for 1891, and guarantees for 1892.

COMMERCIAL GRADES OF ORE FROM VERMILION IRON RANGE, 1891.

COMPOSITION.	Vermilion.	Soudan.	Red Lake.	Minnesota.	Chandler.	Long Lake.
Iron	67.75	65.96	63.49	68.14	63.91	60.06
Silica	1.58	2.27	5.00	1.30	5 10	7.20
Phosphorus	.157	.102	.111	.049	.041	.044
Manganese	.29	.14	.19	trace	.69	.61
Alumina	.98	1.80	.90	1.10	2.90	2.87
Sulphur	trace	trace	.026	trace	trace	.043
Magnesia	trace	.30	.30	.13	trace	.19
Lime	1.00	.54	.71	.56	.87	.31
GUARANTEES.						
Iron	66.66	65.00	62.00	66.66	63.00	60.00
Phosphorus	....	.12	....	.055	.05	.05

In 1891 the Chandler mine produced 354,993 tons of Chandler ore and 20,873 tons of Long Lake ore. The entire product of this mine is bessemer. In some respects this is the greatest mine in the world. Occupying but eighty acres its production for 1892 will be nearly 650,000 gross tons of remarkably uniform ore. Cargo after cargo is sampled at Cleveland that will not vary half of one per cent. in iron content. Under the able direction of Joseph Sellwood the cost of mining has been reduced to less than $1.00 per ton at the depth of 450 feet. It is believed that there is a profit of $1.00 per ton on this ore, providing it brings $4.85 at Cleveland, as it is said to have done in 1892. This estimate is based on the following details:

Cost of Mining, - - - - - - -	$1.00
Royalty, - - - - - - - - -	.35
R. R. Freight to Two Harbors, - - -	1.00
Lake Freight to Cleveland, - - - -	1.20
Insurance, Commission, etc., - - - -	.25
	$3.80

These figures are approximate and are given merely for the sake of indicating the entire feasibility of mining at a profit on the Mesabi, where the cost of mining will be considerably less than at the Chandler, with higher royalties.

The average of the analyses given of the Biwabik ore indicates that in quality it is nearly equal to the Chandler ore. If the expense of placing it on the car, including royalty, were equal, there would be a slight difference [equal to the freight from Ely to Tower, perhaps] in favor of the Biwabik. It might even be possible to sell the ore at $4.00 per ton and still have a nice profit. If in addition to this there are any other directions in which the Biwabik ore can be produced more cheaply than the Chandler, such as smaller mining cost, there is so much more profit. This point will be discussed later.

The analyses of certain standard grades of ore from the other lake Superior ranges is given in the following table.

ANALYSES OF LAKE SUPERIOR IRON ORES.*

MARQUETTE DISTRICT.

NAME OF ORE.	Iron.	Phos.	Silica.	Mang.	Alum.	Magn.	Lime.	Sulphur.
American	65.00	0.045	4.50	......	......	......	......	......
Angeline—Hard	65.50	0.009	......	......	......	......	......	......
Angeline—Hematite	66.38	0.032	......	......	......	......	......	......
Barnum	65.00	0.098	4.70	0.20	0.20	0.35	trace	......
Buffalo	62.33	0.120	6.80	0.37	1.61	0.06	......	......
Cambria	60.00	0.064	7 26	0.37	3.81	0.33	0.62	0.042
Champion, No. 1	67.00	0.040	3.00	......	......	......	......	......
Cleveland, No. 1	65.60	0.104	3.06	0.21	0 99	0.18	0 37	0.037
Cleveland Hematite	60 00	0.060	6.74	0.33	2.35	0.12	0.12	0.011
Cliff Shaft	62.70	0.109	3.45	0.52	1.55	1.15	1.61	0.025
Comrade	60.50	0.100	......	......	......	......	......	......
Detroit	58.60	0.056	8.00	......	......	......	......	......
East New York	60.10	0.055	11.64	0.41	1.11	0.31	0.12	0.029
Humboldt	65.00	0.120	5.00	0.12	0.72	0.26	0.64	0.020
Imperial	57.50	0.280	5.80	0.03	1.71	0.41	1.16	0.045
Jackson	62.00	0.(9)	......	......	......	......	......	......
Lake Superior, No. 1A	64.00	0.116	......	......	......	......	......	......
Lake Superior, Slate	66.00	0.080	3.00	0.03	1.22	0.12	0.48	0 045
Lillie	59.00	0.084	8.69	......	......	......	......	......
Lucy	53.50	0.045	12.05	4.25	......	......	......	......
Michigamme	65.50	0.114	4.57	0.01	0.51	0.11	0.07	0.030
Michigamme, No. 1	62.00	0.055	7.00	0.60	0.80	0.30	1.35	0.030
Milwaukee	62.05	0.105	4 32	0.45	0.60	0 90	1.10	0.080
Mitchell	60.95	0.131	6.85	0.62	1.35	0.30	0.42	0 020
Negaunee	60 00	......	......	......	......	......	......	......
Prince of Wales	62.56	0.106	5.51	0.37	1.70	0.17	0.59	0.053
Prout	53.02	0.041	17.65	......	......	......	......	......
Queen	62.60	0.112	4.65	0.41	1.11	0.31	0.12	0.029
Republic, Magnetic	69.77	0.051	1 78	......	......	......	......	......
Republic, Specular	67.50	0.043	3.01	0.04	0.85	0.07	0.41	0.012
Salisbury Bess	62.00	0.045	4.00	0.22	0.50	0.60	1.00	0.012
Sharon	61.00	0.090	8.00	0.12	0.72	0.26	0.84	0.012
Sheffield	61.00	0.015	......	......	......	......	......	......
South Buffalo	63.80	0.100	4.10	0.31	1.49	0.34	0.82	0.049
Volunteer	60.10	0.070	......	......	......	......	......	......
Winthrop	63.40	0.109	5.37	0.85	0.81	0.11	0.24	0.028
Average	62.33	0.079	4.72	......	......	......	......	......

MENOMINEE DISTRICT.

NAME OF ORE.	Iron.	Phos.	Silica.	Mang.	Alum.	Magn.	Lime.	Sulphur.
Aragon	65.20	0.038	4.68	0.02	0.33	0.01	0.36	0.034
Armenia	60.80	0.188	8.69	0.11	1.33	0.39	0.66	0.022
Chapin	62.13	0.068	4.20	0.26	1.08	2.71	0.81	0.001
Commonwealth	57.70	......	......	......	......	......	......	......
Corbett	58.20	0.675	4.37	0.31	3.10	0.62	0.78	0.041
Crescent	64.55	0.044	3.35	0.15	0.67	1.64	0.50	......
Cyclops	61.00	......	......	......	......	......	......	......
Dunn	60.60	0.344	4.81	0 22	2.98	0.81	0.97	0.036
Eagle	55.20	0.547	5 03	0.02	......	0.81	0.91	0.061
Florence	60.50	0.257	4.05	0.22	0.81	0.64	1.18	0.041
Great Western	......	......	......	......	......	......	......	......
Iron River	59.80	0.356	5.29	0.37	3.41	0.37	0.69	0.028
Ludington	64.59	0.070	......	......	......	......	......	......
Manganate	54.00	0.642	6.00	3.50	......	......	......	......
Mansfield	63.40	0.025	3.56	......	......	......	......	......
Mastodon	58.36	......	......	......	......	......	......	......
Millie	64.06	0 027	3.00	0.08	1.30	0.95	1.10	0.035
Norway	58.00	0.120	12.00	......	......	......	......	......
Paint River	56.40	0.502	3.48	0.37	6.12	0.72	5.58	0.068
Pewabic	65.00	0.010	......	......	......	......	......	......
Rex	55.78	0.080	6.85	......	1.67	......	......	......
Shafer	59.00	......	......	......	......	......	......	......
Vulcan	62.00	......	......	......	......	......	......	......
Youngstown	52.18	0.642	6.00	3.50	......	......	......	......
Average	59.93	0.253	5.33	......	......	......	......	......

*Geo. W. Goetz, Trans. Am. Inst. Min. Eng., vol. xix, p. 59.

VERMILION DISTRICT.

NAME OF ORE.	Iron.	Phos.	Silica.	Mang.	Alum.	Magn.	Lime.	Sulphur.
Braddock	65.17	0.052	4.50	0.13	0.48	0.16	0 56	0.020
Chandler	64.15	0.044	4.30	0 14	2.25	0.19	0.25	0.040
Long Lake	60.20	0.053	7 00	0.54	2.75	0.19	0.25	0.047
Minnesota	67.64	0.051	1 97	0.15	0.04	0.14	0.53	0.020
Nipigon	63.01	0.053	6.75	0 14	0.65	0.20	0.60	trace
Red Lake	62.86	0.099	6.95	trace	0.65	0.20	0 60	trace
Soudan	65.77	0.102	4.25	0.16	0.38	0.17	0 56	0.020
Vermilion	67 31	0.091	2.15	0.15	0.35	0.15	0.02	....
Average	64.50	0.068	4.46	....	....	....	....	....

GOGEBIC DISTRICT.

NAME OF ORE.	Iron.	Phos.	Silica.	Mang.	Alum.	Magn.	Lime.	Sulphur.
Anvil	61.54	0.053	....	....	....	....	....	....
Ashland	63 82	0.039	....	....	....	....	....	....
Aurora	63.36	0.034	4.00	0.03	1.98	0.12	0.04	0.033
Brotherton	62 50	0 037	6.13	0.49	2.98	0.39	0.16,	0.070
Cary	58.84	0 062	5.20	....	....	3.66	....	....
Eureka	62.00	0.076	6.64	0.48	3.69	0.16	0.15	0.015
Germania	59 19	0.058	....	....	....	....	....	....
Hennepin	65.45	0.048	3.53	0.02	0.31	0.02	0.02	0.022
Iron Belt	62.75	0.042	6.33	....	2.44	....	....	....
Ironton	60 55	0.058	....	....	....	....	....	....
Montreal	64.22	0.053	....	....	....	....	....	....
Mount Hope	62.32	0.029	....	....	....	....	....	....
Norrie	63.72	0.043	3.40	....	....	....	....	....
Pabst	62.34	0.037	4.50	....	....	....	....	....
Palms	62.43	0.049	....	....	....	....	....	....
Ruby	62 50	0.045	4.20	0.49	....	0.16	0.45	....
Section 33, North	64.82	0.045	....	....	....	....	....	....
Sunday Lake	62.00	0.036	....	....	....	....	....	....
Trezona	62.55	0.061	4.44	0.02	0.97	0.03	0.02	0.031
West Cary	54.95	0.054	5.35	7.41	....	....	....	....
Windsor	62.00	0.051	6.30	0.81	3.45	0.31	0.40	0.025
Average	62.09	0.048	5.00	....	....	....	....	....
Average of averages	62.46	0.062	4.88	....	....	....	....	....

It will be noticed that the average of the grades given is higher in iron, but also higher in phosphorus than that of the large number of samples of Mesabi ore in the foregoing table. It is not claimed that this average is a correct one of the product of the ranges represented, but it is claimed that it is similar to the average obtained from the various Mesabi analyses, and the comparative high grade of the latter ores is shown thereby. It is unlikely that any ore will ever be shipped to Cleveland of as low grade as the lowest in the table, but it is certain that there will be grades of Mesabi ore as low in phosphorus and as high as or even higher in metallic iron than any hematite ore in the list, and that in large quantity.

It is hardly necessary to refer to the fact that southern ores are very much lower grade than lake Superior ores. Their proximity to the coal field and the furnace is the only feature that enables them to compete with the northern ores at present, and if an unlimited amount of high grade lake Superior ore can be profitably deposited

in Cleveland at a reduction of fifty cents per ton below the present market price, most of the southern furnaces will be forced to suspend operations.

From recent experiments in New York and New Jersey it appears probable that a large amount of concentrated iron ore may be put upon the market in the next few years and become an active and important competitor of the lake Superior district. It is also reliably reported that the Sigua and Juragua districts of Cuba will soon ship several hundred thousand tons per annum of high grade ore to this country, and that they can do it at a profit with the present duty of 75 cents per ton. When shipped to this country for manufacture and exportation, foreign ores may obtain a rebate of the tariff paid for importation. This will be done to a considerable extent in the future.

All these facts indicate that the price of bessemer ore will tend to be lower rather than higher, and Mesabi mine owners may well be congratulated that to the excellent quality of their ore is added the combination of great abundance advantageously situated for very cheap mining.

METHOD OF PROSPECTING.

There is nothing particularly novel or original in the manner in which prospecting is conducted on the Mesabi. An illustration in Agricola's De Re Metallica of a test pit in the sixteenth century shows a windlass operated by a crank at each end almost identical with those employed here three hundred years later. The ancients used two buckets to save time and labor in hoisting. Fig. 7.

The pits are rectangular and vary greatly in diameter. They are seldom timbered below the top of the ore unless very deep and wet. During the winter time pits are sunk in favorable situations to the depth of more than one hundred feet with pick and shovel unaided by a single drill hole or blast of powder. In the spring, however, surface water bothers greatly and pumps are needed. At times there are strata of hard ore or a capping of rock to be penetrated. Drilling and blasting are then resorted to.

The ore is hoisted out in buckets and piled up around the mouth of the pit in a circular dump or stock pile. Plate No. V. is an illustration of a windlass and dump. When the pit is more than one hundred feet in depth the operation of hoisting by hand is a very slow one, and a "bent" is sometimes arranged for hoisting by horse power and dumping into a tram car. This method was first employed on the Mesabi at the Biwabik in the northeast drift at pit No. 15. On Plate No. V. is also an illustration of the bent.

TEST-PITTING AT THE BIWABIK MINE.

CAMPS AT THE WYOMING MINE.

If the ore deposit lies in a rock-rimmed basin there is considerable water in the ore. If it lies on a hillside and is of considerable extent the water filters down through the ore to the basal quartzyte and the upper part of the ore body is quite dry even in very wet seasons. From this it follows that the presence of water in an ore

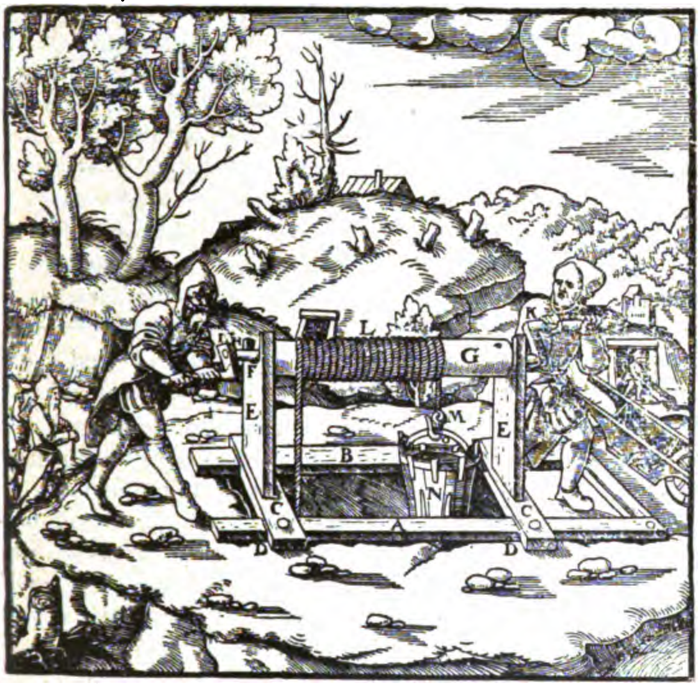


Fig. 7. Test-pitting in the sixteenth century.

pit is simply an indication that it cannot get away, while its absence is a sign that it can escape, probably by filtering down in the ore, which is therefore concluded to be of considerable amount. The significance of the various rocks and their usual appearance have already been discussed.

Mines Now Opened Up.

Biwabik.

After the discovery of the Mountain Iron mine in 1890, described in the first portion of this article, no further discoveries of importance were made until about a year later, when an explorer named John McCaskill saw traces of soft ore in the roots of an over-turned tree in section three, T. 58–16. This led to the discovery of the Biwabik, Cincinnati, Canton, Hale and Kanawha mines. Credit for

the actual discovery of the ore deposit on the Biwabik must be given to Capt. J. A. Nichols. He directed the work which succeeded in making this discovery in August, 1891. Capt. J. G. Cohoe was put in charge of the work here and sunk fifteen test pits during the winter of 1891–'92. It would be somewhat peculiar if the first and second mines to be discovered should turn out to be the best two mines on the range.

In the last part of April the Biwabik Mountain Iron Company leased three forties in sections two and three, T. 58–16, to Mr. P. L. Kimberley, of Sharon, Pa. The lessees are required to mine at least 300,000 tons per annum and to pay a royalty of 50 cents per ton. This deal was the result of an examination of the early developments on the range made by Mr. J. T. Jones, the superintendent of the Hamilton Ore Company, of Iron Mountain, Mich. Work of exploration was continued in a systematic manner and soon became the model for such work on the range. The test pits were rapidly increased in depth and number, and the result showed the wisdom and foresight of Messrs. Jones and Kimberley in the selection of this property out of all those so far discovered on the range. Records of some of their test pits may be seen on page 138. By the time these test-pits were completed it was evident to the unprejudiced observer that here is the greatest deposit of ore known on the range if not in the whole Lake Superior district. Millions of tons of soft hematite, averaging 63 per cent. iron and .045 phosphorus, are here found within one hundred feet of the surface of the ground. It is safe to say that this mine under its present management will eclipse all former records for cost of mining and number of tons produced in a given length of time. There may yet be larger deposits found on the Mesabi, but so far the Biwabik is chief. The Mountain Iron may prove to be its equal, and at present is a good second, but the number of cubic feet of ore reasonably to be estimated as "in sight" at the Biwabik exceeds that of any two other mines yet opened up.

Cincinnati.

Adjoining the Biwabik on the east is the Cincinnati. This is also a fine property. It does not seem to get the credit it deserves among those familiar with the range, perhaps because it happens to suffer somewhat in comparison with the Biwabik adjoining, which is a larger property and has been more extensively developed. For several months no property on the range could make a better showing as to quantity and quality of ore than the Cincinnati. Subsequent development revealed others equally as good,

but that was only to be expected. Later development on this property also showed the ore to be more extensive than the owners themselves believed it originally.

This mine is leased to the Standard Ore Company, who have agreed to mine at least 150,000 tons each year at a royalty of 55 cents per ton.

The development of this property was largely under the charge of Capt. Edward Florada and Capt. Carlin.

Canton.

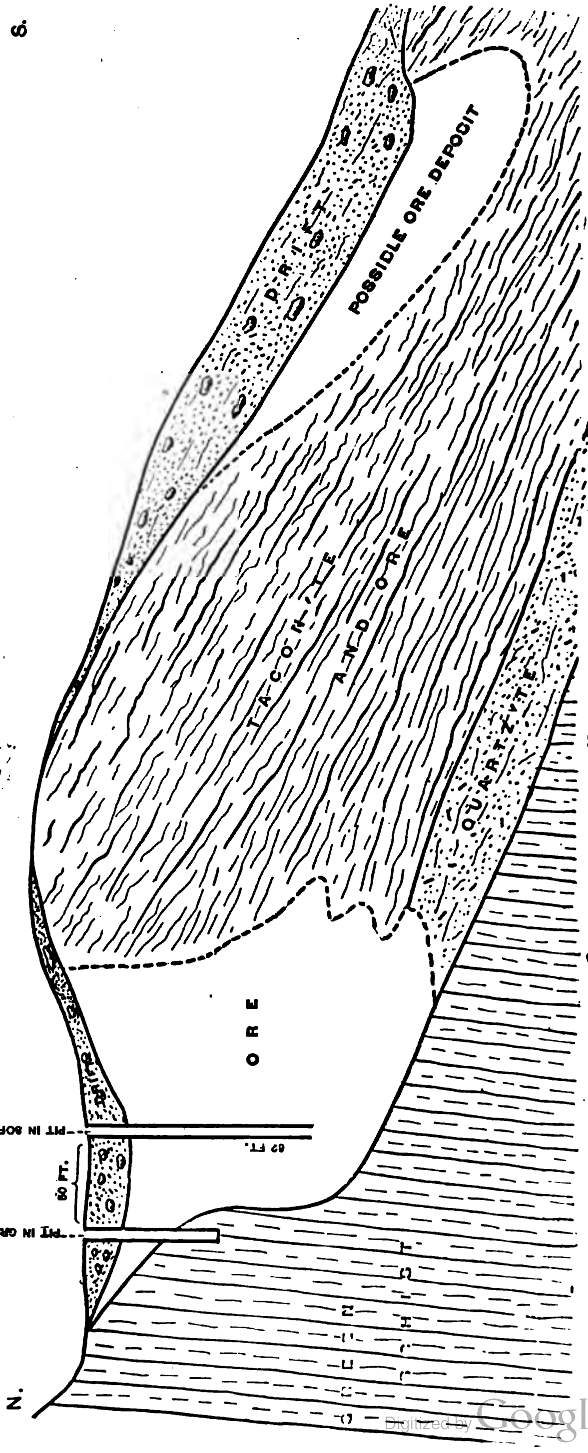
This property, owned by the Minnesota Exploration Company, lies on the west side of the Biwabik. The ore here was discovered by Mr. Edgar Brown. Much of it is non-bessemer gœthite. It is probable that there is better ore to be found here at a greater depth. Work is now being vigorously prosecuted under the direction of President D. H. Bacon of the Minnesota Iron Company.

Kanawha and Hale.

The Kanawha Iron Company did considerable exploration work in the S. E. ¼ N. W. ¼ section 1, T. 58–16, in April, 1892, and found a considerable depth of ore in a series of test pits located east and west along the north side of the forty. The width of the deposit is not yet proven to be great here, the ore appearing to lie in a rather narrow gorge. The peculiar relation of the ore deposit at this place to the green schist or "greenstone" is shown by Fig. 8.

Pit No. 1 went through the ore at the depth of thirty-eight feet into an unaltered portion of the taconyte. On this property and the Hale, which lies just to the east, the fact is plainly shown that the drainage slope considered necessary to facilitate the replacement process does not always consist of the rocks of the Taconic formation above the ore deposit itself. The flow of waters which has accomplished the replacement and concentration may have come from a ridge of Keewatin green schist or Archæan granite. At this place there are two pits fifty feet apart, one in fifty-five feet of ore and the other in green schist. The schist is the same as that seen elsewhere on the range and lies unconformably beneath the Taconic rocks. It dips here N. 85°, while the dip of the ore is S. 10°. The ore occupies a gorge at the contact line between the two formations. The same deposit in the same relative position extends eastward across the Hale forty. The bare ridges of green schist rise much higher northward, and drainage is off the schist ridges into the valley in which the ore is found. The fact that the ore on these two properties is largely a non-bessemer

Fig. 8.



SITUATION AT THE KANAWHA AND HALE.

gœthite is an indication that the replacement is not so perfect in this situation as when the entire slope is composed of the Taconic iron formation.

Missabe Mountain.

A pit located with very good judgment by Capt. J. G. Cohoe, one of the earliest and best explorers on the range, encountered ore on this property, N. E. ¼ section 8, T. 58–17, in the first pit sunk, at the depth of thirteen feet. This was in the last of March, 1892. The first ore discovered in this township was on this property. Other pits on the same land revealed a large deposit of ore of good quality, and in about four months a lease was made to H. W. Oliver, of Pittsburgh, on a guaranteed output of 400,000 tons annually, at the high royalty of 65 cents per ton. The income of this company is thus assured to be more than a quarter of a million of dollars from this property alone. An advance royalty of $75,000 was paid by Mr. Oliver. So quickly are iron mines developed and turned into cash on the Mesabi.

Ohio.

The Ohio Iron Company moved their workmen to the corner of their property nearest the first pit on the Missabe Mountain in April, and were rewarded by finding soft blue hematite of excellent quality in several pits. Early in June this property was leased to James Sheridan, of Duluth, and others, who agreed to pay $97,500 a year in royalties at the rate of 65 cents per ton.

Lake Superior.

In February or March ore was found in the northeast quarter of section 22, T. 58–20, on the land of the Lake Superior Iron Company. This was the fourth township in which ore had been found and its discovery added greatly to the already intense excitement in Duluth. The statement was often made that the whole country was full of iron ore and that a test-pit could hardly fail to find it. Some were of the opinion that iron ore would be so abundant as to be worthless, and that the mines were equally so. It is needless to say that this opinion was held by those who were ignorant of the immense consumption of iron in this country. It is also superfluous to add that this idea was exaggerated beyond all bounds.

Several test pits found ore on the property of this company, both at the first location and at another farther west. As yet no sublease has been made by this corporation, and their intention may be to do their own mining.

At the Mountain Iron mine the quartzyte is underlain by granite as it is also at the Lake Superior.

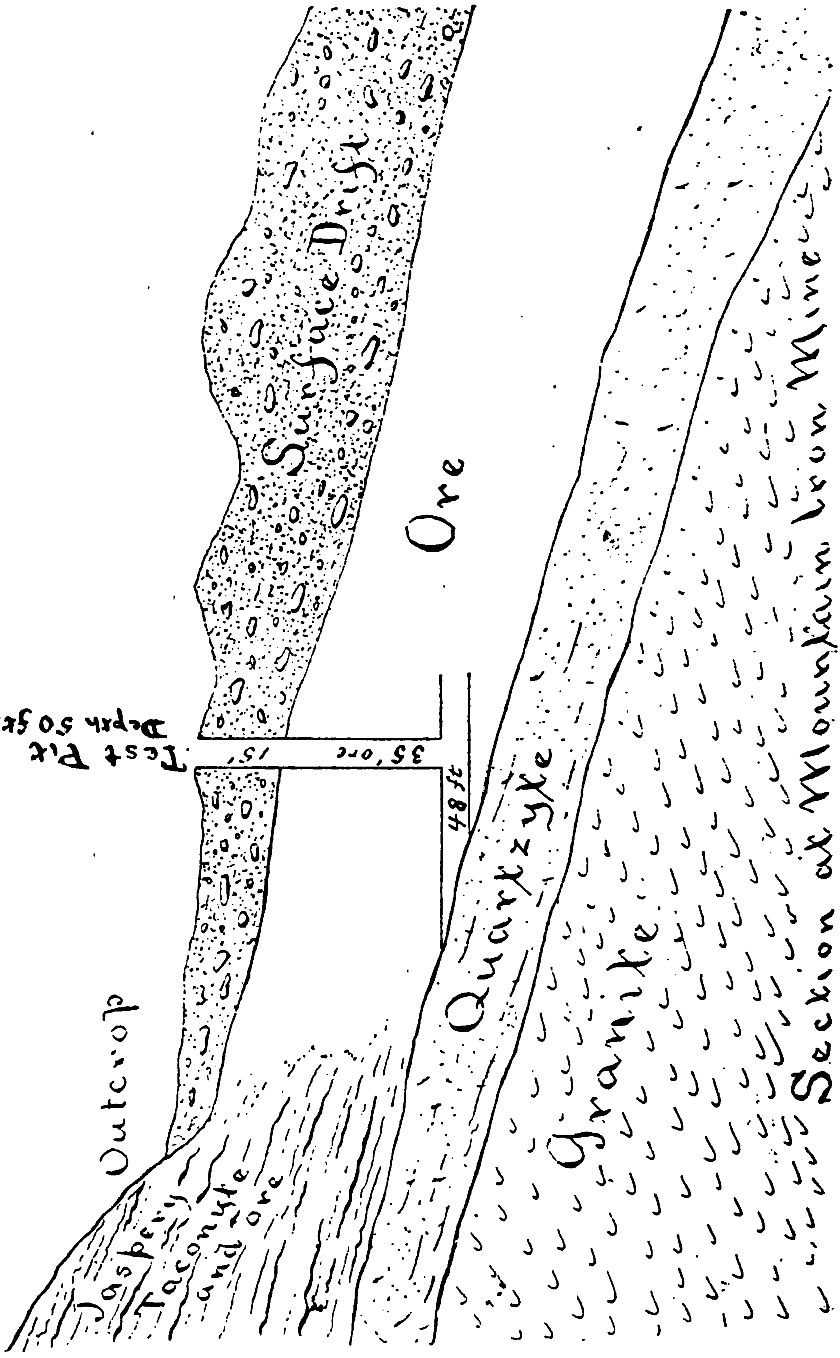


Fig. 9. Section at the Mountain Iron mine.

New England.

In May a fine body of ore was discovered by John Owens on the property of the New England Iron Company, N. W. ¼ N. W. ¼ section 9, T. 58–17. Later developments have shown the existence of nearly forty acres of ore, and most of it is the peculiar soft blue ore, which is the best on the range. In August this property was subleased to Capt. N. D. Moore and others at a royalty of 55 cents per ton and an advance royalty of $50,000. This company controls other lands favorably situated for the existence of merchantable ore bodies.

Virginia.

The Virginia Iron Company also found ore in the N. E. ¼ S. E. ¼ section 8, T. 58–17, during the month of May. This property was leased in August for a valuable consideration. A number of test pits indicate that there is ore over a large area on the land of this company. Like the New England, Wyoming, Lone Jack, Kanawha and others, it belongs chiefly to A. E. Humphreys & Co., who were fortunate in their selection of lands and who spared no expense in the rapid and thorough exploration of them. The phenomenally quick development of the new range is due perhaps more largely to their efforts than to those of any other single firm or individual. Their confidence in the district and their earnest efforts to develop it deserve abundant thanks and reward.

"Paddack's."

Ore was found on the S. W. ¼ N. E. ¼ section 3, T. 58–18, east of the Mountain Iron mine, in May. This was the second property in this township to show a good body of ore. The glacial drift here exceeds fifty feet in depth and water is troublesome, but the body of merchantable ore appears to be of considerable extent.

Lone Jack, Wyoming, Security, Great Western and Rouchleau.

Along in May ore was found on the above properties, all situated in T. 58–17. There is a large bend in the green schist ridge in this township and the largest group of mines on the range is situated on the flanks of this loop or bend. As will be seen from the map these mines follow the curving line of the greenstone ridge, and occur on its flanks, irrespective of the direction it may happen to assume. No detailed description of each property and its develment will be given here, for the work is not sufficiently advanced to warrant it and the main features are similar to those already described on other properties.

There is, however, one peculiar occurrence on the Lone Jack and Missabe Mountain to which reference has already been made.

There appears to be a pre-glacial gorge formerly excavated by some stream flowing in a westerly direction down from the green schist ridge across the Lone Jack and Missabe Mountain into the valley in the southwest part of the township. This gorge was in some way filled with gravel, at the present time composed principally of round, water-worn fragments of hard ore. The drift mantle was subsequently spread over the top of the filled gorge and the ore on both sides of it. At the bottom of this gravel-filled gorge is a stratified layer of light colored kaolinic material which varies in thickness from a few inches to twelve feet. Beneath this stratum of kaolin is soft blue hematite similar to that found by test pits north and south of the supposed gorge on both the Lone Jack and Missabe Mountain. The depth of this ore gravel in the gorge is more than sixty feet. The test-pits sunk on both sides of it encounter ore at the depth of from eight to fifteen feet as the thickness of the drift varies. The so-called ore-gravel is mostly hard, dark colored hematite and is cemented by a soft ferruginous paste containing more or less of the kaolinic matter. It is not certain that this gravel was ore when it was deposited in its present position, but it does appear likely that it is not a constituent part of the Taconic strata. The fine deposit of kaolin which separates it from the blue ore below and on the sides was perhaps derived from the detritus of the feldspathic green schist, although it is similar to material found elsewhere at the base or lower edge of deposits of ore, and may thus be a product of chemical alteration *in situ*.

McKinley.

In December, 1891, ore was found on the McKinley, N. W. ¼ S. E. ¼ section 8, T. 58–16. During January work progressed rapidly under the direction of Mr. D. McKinley. Three pits were sunk in good soft blue hematite. Having proven the existence of a good mine here work ceased, until railroad facilities could be obtained, before the full extent of the deposit was revealed. The property is a large one and there is abundant opportunity for a very fine deposit of ore.

During the winter of 1891–'92 work was vigorously prosecuted on all these properties, and the discovery of such a large amount of ore produced quite an excitement in Duluth and among northwestern iron miners, in the months of January, February and March, 1892. Many new companies with a very large capital stock were organized, and the work of searching for iron deposits was begun in dozens of camps in the dead of winter. Log camps were erected

and tons of supplies were taken on runners to the various locations west of Mesaba station on the Duluth and Iron Range railroad. The organization of these companies was a matter of speculation. The lands were held under State or private lease at a royalty of 25 or 30 cents per ton, or in fee, and were selected without any knowledge of the region or the properties or the possibility of the discovery of ore thereon. It was to be expected that many companies would be disappointed in the search for ore and that the expense of operating would soon drain the exchequers of others. This was in fact the case, but it must be admitted that the number of successful ones was surprisingly large.

Other discoveries of ore.

There are authentic reports of the discovery of merchantable ore in townships 58–20, 58–21 and 57–22, on the lands of the Washington, Mesabi Chief and Lake Superior Iron companies, as well as on land under lease to J. M. Longyear. These have not been visited recently by the writer. Neither has the Diamond mine in 56–24. This mine has been operated for several years under the superintendence of Mr. E. W. Griffin, of Minneapolis. The results were not at first satisfactory, and considerable trouble was experienced with water. It is reported that the work is at present being conducted in a body of good soft ore. The Gunflint Lake Iron Company, under the direction of Mr. John Paulson, is preparing to mine the magnetic ore on the eastern end of the Mesabi range in township 64–5. The Port Arthur, Duluth and Western railroad is in operation to a point near these deposits.

LIST OF SUB-LEASES ALREADY MADE.

Mine.	Royalty.	Advance royalty.	Minimum output, tons.
Cincinnati. [To Standard Ore Co.] . . .	$.55	$25,000	150,000
Biwabik. [To P. L. Kimberley.]	.50	. . . . . .	300,000
Biwabik. [To Berringer et al.]	.50	. . . . . .	*100,000
Virginia. [To Weimer et al.]	.50	25,000	50,000
Wyoming. [To A. J. Decker.]	.30	40,000	25,000
Wyoming. [To. J. T. Jones.]	.50	. . . . . .	25,000
Wyoming. [To Parkersburg Iron Co.]	.50	30,000	50,000
New England. [To N. D. Moore.]	.55	50,000	150,000
New England. [To J. B. Weimer.] . . .	.50	25,000	50,000
Lone Jack. [To Moore & Foley.]	.65	. . . . . .	50,000
Missabe Mountain. [To H. W. Oliver]	.65	75,000	400,000
Ohio. [To Jas. Sheridan et al.]	.60	. . . . . .	150,000
Hale. [To F.A.Bates and H.P.Barbour]	.50 & .40	. . . . .	50,000
			1,550,000

*50,000 tons each alternate year.

LIST OF MINING COMPANIES INCORPORATED IN MINNESOTA DECEMBER 1, 1890, TO SEPTEMBER 1, 1892.*

[The name of the company is followed by the place of its principal office, the amount of capital stock, number of shares, date of incorporation and names of incorporators.]

Alaska Mexican Gold Mining Company; St. Paul; $1,000,000; 200,000 shares; Nov. 17, 1891. S. M. Magoffin, F. S. Kirkpatrick, J. T. Rogers.

Allegheny Iron Mining and Milling Company; Duluth; $1,500,000; 150,000 shares; May 11, 1892. C. C. Merritt, W. O. Tillotson, P. Hamil, Grant Wyatt, D. W. Evans.

American Mining Company; Minneapolis; $3,000,000; 30,000 shares; March 1, 1892. D. M. Clough, J. B. Sutphin, R. Jamison, F. G. James.

Anderson Iron Company; Duluth; $1,000,000; 40,000 shares; July 16, 1891. A. R. Macfarlane, W. C. Sherwood, J. T. Hale.

Athens Iron Company; Duluth; $3,000,000; 30,000 shares; March 3, 1892. L. Merritt, A. Merritt, R. H. Palmer.

Atikokan Iron Company; Duluth; $250,000; 2,500 shares; Jan. 19, 1892. S. Meniece, A. Snyder, W. Getty, E. J. McLaughlin, M. McManus, J. I. Gilbert, W. McRae, A. P. Cook.

Aurora Iron Company; Duluth; $3.000,000; 30,000 shares; April 8, 1892. J. McKinley, A. E. Humphreys, P. S. Bemis, J. Billings, G. N. Bissell.

Bessemer Iron Development and Mining Company; Duluth; $100,000; 1,000 shares; Aug. 23, 1892.

Bessemer Iron Company; Duluth; $3,000,000; 120,000 shares; Feb. 27, 1892. L. J. Hopkins, G. H. Claypool, H. S. Mahon, C. J. Kershaw, A. E. McCordic, W. B. Silvey, W. G. Crosby, E. C. Jones.

Biwabik Mountain Iron Company; Duluth; $2,000,000; Oct. 9, 1890; $3,000,000; 30,000 shares; Oct. 17, 1891. L. Merritt, E. H. Hall, J. J. Wheeler.

Boston Iron Company; Duluth; $2,000,000; 20,000 shares; March 1, 1892. J. McKinley, G. W. Buck, G. F. Piper, J. T. Hale.

Boston Iron Company; Duluth; $3,000,000; June 16, 1892. Changed to McCaskill Mining Company.

Bradley Iron Company; Duluth; $2,000,000; 20,000 shares; March 1, 1892. H. C. Hanford, G. F. Piper, E. L. Bradley.

Buckeye Iron Company; St. Paul; $3,000,000; 30,000 shares; March 4, 1892. F. Barrett, E. D. Sawyer, J. H. James, W. W. Braden, J. H. Baker.

Buffalo Land and Exploration Company; Duluth; $125,000; 125,000 shares; July 27, 1892. W. E. Richardson, C. Adams, J. T. Hale, H. W. Coffin, O. H. Hewit, D. G. Cash, J. D. Stryker.

* For a list of all the companies previously incorporated in Minnesota for the purpose of mining see Bulletin No. 6, "The Iron Ores of Minnesota," p. 335.

Camden Iron Company; Duluth; $1,000,000; March 25, 1892; $1,200,000; 12,000 shares; April 5, 1892. J. G. Williams, J. B. Lovell, H. G. Ingersoll, A. J. Decker.

Carnegie Mining Company, The; Duluth; $1,000,000; 10,000 shares; April 4, 1892. S. P. Davidge, E. Zobrlaut, R. F. Fitzgerald, T. E. McGarr, J. R. Bell.

Central American Mining and Improvement Company; St. Paul; $100,000; 20,000 shares; Jan. 4, 1892. W. M. Davis, P. Fletcher, S. M. Magoffin.

Central Vermilion Iron Company; St. Paul; $800,000; 80,000 shares; March 22, 1892. E. A Hendrickson, A. Scheffer, E. J. Hodgson, C. W. Cox, L. E. Judson, Jr.

Champion Iron Company; Duluth; $3,000,000; 30,000 shares; March 1, 1892. W. McRae, J. I. Gilbert, C. F. Howe.

Charleston Iron Company; Duluth; $2,000,000; 20,000 shares; Feb. 11, 1892. J. McKinley, F. Cox, A. E. Humphreys.

Chicago Iron Company; Duluth; $5,000,000; 50,000 shares; Feb. 15, 1892. A. E. Humphreys, E. C. Gridley, J. McKinley, J. T. Hale.

Cincinnati Iron Company; Duluth; $3.000,000; 120,000 shares; Nov. 24, 1891. L. Prichard, F. Woodman, A. E. Humphreys, J. McKinley, J. T. Hale.

Clark Iron Company; Duluth; $3 000,000; 30,000 shares; March 7 1892. M. J. Clark, F. Jewell, M. W. Bates, G. F. Piper, A. B. Upton, C. F. McComb.

Cleveland Iron Company; Duluth; $200,000; 2,000 shares; Jan. 28, 1892. J. McKinley, G. J. Atkins, M. O. Brooks.

Columbia Iron Company; Duluth; $3,000,000; 30,000 shares; March 14, 1892. J. McKinley, D. McKinley, G. S. Ostrum, J. E. Lobdell, S. O. Brooks, T. E. Yerxa, E. B. Swygart, G. M. Bissell, A. C. Clauson.

Columbus Iron Company; St. Paul; $2,000.000; 20,000 shares; March 23, 1892. F. Barrett, W. W. Braden, M. Clark, J. McCarthy, A. S. Bates, M. O. Brooks.

Comstock Iron Mining Company; Duluth; $5,000,000; 50,000 shares; March 11, 1892. G. T. Porter, F. W. Merritt, G. A. Elder, A. D. Thomson, M. Simpson, W. M. Holbrook.

Consolidated Missabe Iron Company; Duluth; $3,000,000; 30,000 shares; March 14, 1892. G. M. Nelson, L. Merritt, R. Jamison, A. Erwin. J. Mather, K. D. Chase.

Cosmopolitan Iron Company; Duluth; $4,000,000; 40,000 shares; March 11, 1892. J. McKinley, F. W. Winship, A. E. Humphreys.

Dayton Iron Mining Company; Duluth; $1,000,000; 10,000 shares; Feb. 29, 1892. J. C. Semple, J. W. Earl, W. P. Strickland, J. F. Landry, N. A. Gearhart, C. A. Long, W. A. Barr, H. P. Haskell, G. F. Copeland.

Detroit Iron Company; Duluth; $3,000,000; 120,000 shares; Feb. 18, 1892. J. T. Hale, F. E. Kennedy, J. M. Root.

Diamond Iron Mining Company, The; Minneapolis; $100,000; 1,000 shares; Aug. 20, 1892. G. F. Warner, A. Richardson, H. H. Smith.

Donald Grant Mining Company; Duluth; $50,000; 500 shares; March 14, 1892.

Duluth Iron Mining Company; Duluth; $200,000; 2,000 shares; March 3, 1892. F. Cox, S. W. Eckman, A Howell.

Duluth Mining Investment Company; Duluth; $50,000; 500 shares; March 16, 1892.

Duluth Ore Company; Duluth; $100,000; 4,000 shares; May 16, 1892. J. R. Berringer, A. H. Stevens, J. B. Weimer.

Elk Iron Mining Company, The; St. Paul; $3,000,000; 30,000 shares; April 13, 1892. C. R. Groff, D. D. Merrill, Jr., W. B. Richards, J. L. Stack.

Gowan Mining Company; Minneapolis; $500,000; 100,000 shares; May 26, 1892. A. H. Linton, R. B. Langdon, R. B. Conkey, C. S. Langdon, J. A. Gowan.

Great Northern Mining Company; Duluth; $2,000,000; 20,000 shares; Jan. 2, 1892; $3,500,000; 35,000 shares; April 2, 1892. G. L. Robbins, E. T. Merritt, J. T. Culbertson, N. B. Merritt, E. R. Brace, T. A. Merritt, R. W. Allnutt, F. W. Merritt, H. A. Wing.

Great Western Mining Company; Duluth; $6,000,000; 60,000 shares; March 5, 1892. A. Merritt. L. Merritt, G. L. Robbins, J. Culbertson, E. T. Merritt, F. W. Merritt, N. B. Merritt, C. C. Merritt, D. B. Searle, C. A. Gilman, M. Simpson.

Guaranty Silver Mining Company; Minneapolis; $500,000; 500,000 shares; June 5, 1891. A. C. Dunn, J. G. Ricke, A. D. Westby, C. D. White, E. Robinson.

Gunflint Lake Iron Company; Duluth; $100,000; 1,000 shares; Mar. 24, 1892. J. Paulson, K. Kortgaard, O. D. Kinney.

Hale Iron Company; Duluth; $3,000,000; 30,000 shares; Mar. 2, 1892. J. T. Hale, E. C. Gridley, J. Norton.

Henderson Mountain Mining and Milling Company, The; St. Paul; $100,000; 1,000 shares; July 27, 1892. W. E Nichols, H. J. Chittenden, L. Blanden, W. A. Jones.

Henrietta Iron Company, The; Minneapolis; $50,000; 500 shares; April 27, 1892. G. F. Moulton, O. J. Nevitt, J. Paulson, G. A. Morse, W. H. Cooper.

Hidden Treasure Silver Mining Company; Minneapolis; $100,000; 100,000 shares; Dec. 28, 1891. D. McKenzie, N. Campbell, L. Kimball, F. W. Nevens, W. R. Steadman.

Horton Mining Company; Duluth; $500,000; 50,000 shares; Jan. 28, 1892; $1,000,000; 100,000 shares; Feb. 20, 1892. G. W. Horton, S. G. Wightman, R. H. Harris, W. E. Worden, S. S. Smith, H. B. Moore, W. D. Edson, R. P. Edson.

Imperial Mountain Iron Mining Company, The; St. Paul; $1,000,000; 10,000 shares; April 11, 1891. J. P. Heatwole, J. Roach, A. B. Kelly, S. Finkelson, L. D. Baird, W. B. Joyce, J. J. Furlong.

Iron Belt Mining Company; Duluth; $1,000,000; 40,000 shares; Mar. 1, 1892. A. J. Trimble, F. Hibbing, L. E. Judson.

Iron Cliff Mining Company; Duluth; $3,000,000; 30,000 shares; March 5, 1892. H. Keller, J. C. Flynn, J. Kraker, S. S. Titus, J. R. Howes, W. N. Holbrook, M. Johnson, A. B. Plough, T. G. Alvord, N. C. Thrall, J. B. Sutphin, *et al.*

Kakina Iron Company; Duluth; $1,000,000; 40,000 shares; Dec. 4, 1891. W. H. Fisher, D. Grant, D. H. Merritt.

Kaministique Iron Company; Minneapolis; $100,000; 10,000 shares; Dec. 3, 1891. S. H. Hall, H. S. Smith, G. A. Castle, R. D. Arundell, C. L. Stacy, A. M. Hillman, E. W. Ginter.

Kanawha Iron Company; Duluth; $2,000,000; 20,000 shares; Feb. 15, 1892. A. E. Humphreys, J. T. Hale, G. E. Milligan.

Kentucky Iron Company; Duluth; $1,000,000; 10,000 shares; March 8, 1892. F. W. De Vey, W. H. Smallwood.

Keystone Iron Company; Duluth; $3,000,000; 30,000 shares; March 4, 1892. C. Markell, A. C. Otis, F. G. Stevens, W. E. Richardson, H. W. Pearson, E. R. Brace, F. B. Lazier, J. T. Hale, C. L. Codding.

Lackawanna Iron Company; Duluth; $3,000,000; 30,000 shares; Mar. 3, 1892. F. L. De Forest, W. G. Park, M. J. Davis, E. F. Clark, J. A Taylor.

Lake Superior Iron Company; Duluth; $5,000,000; 200,000 shares; March 17, 1892. A. J. Trimble, W. D. Vernam, W. H. Buffum, F. Hibbing, W. Munro.

Licking Mining Company; St. Paul; $3,000,000; 30,000 shares; April 22, 1892. F. Barrett, W. W. Braden, A. W. Thurman, W. V. Marquis, J. H. Newton.

Lincoln Iron Company; Duluth; $3,000,000; 30,000 shares; March 19, 1892. H. H. Myers, F. Cox, A. Howell.

Little Mesabi Iron Company; Minneapolis; $3,000,000; 30,000 shares; March 15, 1892. R. W. Cavenaugh, E. S. Bean, G. H. Dodge, E. F. Dodge, A. C. Paul.

Lone Jack Iron Company; Duluth; $500,000; 5,000 shares; Aug. 26, 1892. A. E. Humphreys, G. E. Milligan, A. Howell.

Lucky Hit Mining and Milling Company; Minneapolis; $250,000; 250,000 shares; March 11, 1891. S. Parker, W. F. Albee, J. L. Parker.

Mallmann Iron Mining Company; Duluth; $1,000,000; 100,000 shares; March 5, 1892. A. H. Viele, A. J. Trimble, F. L. Cowen. Increased capital stock.

McCaskill Mining Company; Duluth; $3,000,000; 30,000 shares; June 16, 1892. Changed from **Boston Iron Company.**

McKinley Iron Company; Duluth; $5,000,000; 50,000 shares; May 25, 1892. W. McKinley, J. Charnley, J. McKinley, G. N. Bissell, D. McKinley, J. Billings.

Merritt Nickel Mining Company; Duluth; $2,000,000; 20,000 shares; May 24, 1892. F. W. Merritt, G. W. Mann, W. H. Prescott.

Mesabi Chief Iron Company; Duluth; $3,000,000; 30,000 shares; March 1, 1892. W. B. Gardner, J. C. Mishler, S. G. Wightman, R. F. Willcuts, C. D. Smith.

Mesabi Iron Range Mining Company; St. Paul; $4,000,000; 40,000 shares; March 27, 1892. S. McClure, S. Matthews, J. J. Howe.

Minawa Iron Company; Duluth; $50,000; 500 shares; Aug. 20, 1891. W. H. Fisher, D. H. Merritt, J. H. Upham, L. Merritt, W. A. Barr.

Minneapolis and Webb City Mining Company; Minneapolis; $100,000; 10,000 shares; Aug. 18, 1891. F. A. Fisher, W. H. Mitchell, W. M. Barrows, D. G. Michell, S. P. Channell, J. A. Bowman, S. A. Reed, J. B. Starkey, J. H. Clark.

Minneapolis Iron Company; Minneapolis; $3,000,000; 30,000 shares; Feb. 23, 1892. E. M. Mabie, A. R. McGill, G. L. Becker, C. N. Smith, W. S. Milnor, J. J. Ankeny.

Minneapolis Mineral Land Company; Minneapolis; $50,000; June 19, 1891. J. I. Best, J. S. Lane, C. E. Brewster, L. M. Lane, J. F. Calhoun, M. McKinney, W. Miller, E. J. Edwards, E. I. Ewing, O. Jones, O. F. Schmid.

Minneapolis Mining and Milling Company; Minneapolis; $500,000; 500,000 shares; Dec. 26, 1891. J. Pye, S. Parker, W. Hartley, W. F. Albee, J. L. Parker.

Minnehaha Mining and Milling Company; Minneapolis; $500,000; 500,000 shares; April 26, 1892. G. Danforth, L. P. Crevier, F. H. Wendell, K. E. Brewster, D. F. Strobeck.

Minosin Iron Company; Duluth; $50,000; 500 shares; Aug. 20, 1891. W. H. Fisher, J. H. Upham, D. H. Merritt, L. Merritt, W. A. Barr.

Missabe Central Land and Exploration Company; Duluth; $100,000; 10,000 shares; Jan. 2, 1892. A. Merritt, R. H. Palmer, J. Helmer.

Missabe and Northern Townsite Company; Duluth; $50,000; 500 shares; March 17, 1892. L. Merritt, R. H. Palmer, N. B. Merritt, A. Merritt.

Missabe Mountain Iron Company; Duluth; $3,000,000; 30,000 shares; Feb. 4, 1892. L. Merritt, J. E. Merritt, K. D. Chase.

Missabe Monarch Iron Company; Duluth; $3,000,000; 30,000 shares; March 12, 1892. L. Merritt, R. H. L. Jewett, W. P. Jewett.

Missouri Iron Company; Duluth; $50,000; 5,000 shares; Aug. 4, 1892. L. J. Taussig, A. W. Taussig, T. Bloomfield.

Myrna Iron Mining Company; Duluth; $200,000; 100,000 shares; Feb. 14, 1891. T. H. Pressnell, F. Hibbing, R. D. Mallet, A. J. Trimble, F. I. Tedford.

New Castle Iron Mining Company; Duluth; $250,000; 25,000 shares; April 4, 1891. A. E. Humphreys, F. I. Tedford, F. Hibbing, T. H. Pressnell, J. A. Boggs.

New England Iron Company; Duluth; $3,000,000; 30,000 shares; March 15, 1892. A. E. Humphreys, J. McKinley, A. J. Blethen, L. Swift, Jr., W. H. Lynn.

New York Iron Company; Duluth; $3,000,000; 120,000 shares; Mar. 1, 1892. C. C. Merritt, A. R. Merritt, H. W. Coffin, J. T. Hale, E. T. Merritt.

Nibiwa Iron Company; Duluth; $50,000; 500 shares; Aug. 20, 1891. W. H. Fisher, J. H. Upham, D. H. Merritt, L. Merritt, W. A. Barr.

Northern Light Iron Company; Duluth: $2,000,000; 20,000 shares; March 31, 1892. A. Michaud, A. I. Scarlett, S. Clark, A. M. Cox.

Ohio Iron Company; Duluth; $50,000; 2,000 shares; Aug. 12, 1892. J. Sheridan, J. T. Jones, J. B. Weimer.

Ohio Mining Company; Duluth; $1,000,000; 100,000 shares; Feb. 1, 1892; $3,000,000; 30,000 shares; April 18, 1892. J. E. Campbell, E. D. Sawyer, W. J. Hilands, C. F. Nester, R. S. Munger, M. R. Baldwin, T. H. Pressnell, J. K. Persons, F. Barrett, S. R. Ainslie.

Oneota Iron Mining Company; Duluth; $1,500,000; 15,000 shares; March 1, 1892. F. W. Merritt, J. Frazer, G. W. Mann, G. Wyatt, J. M. McLennan, E. F. Clarke.

Outcrop Iron Mining Company; St. Paul; $500,000; 5,000 shares; May 10, 1892. C. A. Hutchinson, G. Lill, J. F. Whiting, D. M. Case, F. Barrett.

Pacific Mining Company, The; Duluth; $500,000; 5,000 shares; May 6, 1892. A. Erwin, G. N. Baxter, E. H. Hall, G. N. Nelson, R. Jamison.

Palisade Mining Company; Minneapolis; $250,000; Oct. 21, 1891. J. F. Calhoun, L. M. Lane, J. S. Lane, M. McKinney, E. J. Edwards.

Parkersburg Iron Company; Duluth; $100,000; 1,000 shares; Sept. 5, 1892. J. Billings, P. S. Bemis, F. Cox.

Pennsylvania Iron and Steel Company; Duluth; $3,000,000; 30,000 shares; March 5, 1892. Nels Hall, D. W. Evans, S. W. Clark, A. T. Scarlett, N. A. Gearhart, A. C. Pearsons, G. Wyatt.

Pipe Lake Nickel Mining Company; Duluth; $500,000; 50,000 shares; June 9, 1891. R. Forbes, G. N. Stevenson, W. H. Trescott, J. T. Watson, M. Douglas.

Pittsburgh Iron Company; Duluth; $100,000; 4,000 shares; Dec. 12, 1891. W. McKinley, J. McKinley, A. J. Trimble.

Poca Iron Company; Duluth; $50,000; 500 shares; June 9, 1892. F. Cox, A. Howell, S. W. Eckman.

Portage Red Sandstone Company; Duluth; $100,000; 1,000 shares; July 7, 1891. J. D. Lloyd, F. B. Chew, J. H. Hellyer, C. W. McFadden, C. T. Le Tourneau.

Putnam Iron Company; Duluth; $3,000,000; 30,000 shares; March 2, 1892. J. T. Hale, E. C. Gridley, S. R. Payne, J. P. Morrow, E. G. Chapman, H. S. Stearns, J. Sheridan, C. d'Autremont.

Republic Iron Company; Duluth; $3,000,000; 120,000 shares; March 22, 1892. P. M. Graff, F. W. Eaton, J. G. Brown, R. J. Ryan, A. Erwin, G. M. Nelson, R. Jamison.

Rouchleau Iron Company; Duluth; $5,000,000; 50,000 shares; Mar. 18, 1892. L. Rouchleau, F. W. Higgins, G. Gilbert, G. F. Piper, C. E. Shannon, G. W. Buck, T. B. Mills.

Security Iron Company; Duluth; $3,000,000; 30,000 shares; March 1, 1892. J. T. Hale, E. T. Merritt, G. W. Buck, G. F. Piper, R. H. Palmer.

Security Land and Exploration Company; Duluth; $100,000; 10,000 shares; Dec. 30, 1891. G. W. Buck, G. F. Piper, J. T. Hale, N. B. Merritt, R. H. Palmer.

Shaw Iron Company; Duluth; $3,000,000; 30,000 shares; Dec. 21, 1891. D. W. Scott, J. E. Davies, A. R. Merritt, N. B. Merritt, R. H. Palmer.

Sheridan Iron Company; Duluth; $1,000,000; 100,000 shares; Dec. 8, 1891. C. E. Shannon, W. C. McComber, R. H. Harris, J. H. Harris, C. M. Gray, A. C. Otis, G. R. Laybourn.

Silver Chief Mining Company, The; Minneapolis; $500,000; 500,000 shares; Aug. 18, 1892. M. N. Price, B. F. Moore, C. L. Mendel, F. M. Hutchinson, F. L. Favor, F. E. Mix, W. F. Thayer.

Southern California Smelting and Refining Company, The; Los Angeles; $500,000; ——— shares; Sept. 5, 1892.

Standard Ore Company, The; Duluth; $1,500,000; 60,000 shares; Aug. 5, 1892. H. W. Oliver, F. A. Bates, H. P. Barbour, A. D. Thompson, B. C. Church, C. A. Congdon.

Steep Rock Mining and Improvement Company; Duluth; $50,000; 500 shares; May 13, 1892. L. S. Franklin, H. C. Ash, A. E. Walker.

Stowell Iron Company; Duluth; $1,000,000; 100,000 shares; Feb. 16, 1891. W. H. H. Stowell, B. E. Baker, G. F. Long, A. C. Jamison, T. H. Pressnell, S. F. Boyce, F. I. Tedford, J. Zimmermann, L. W. Hizar, F. Barrett.

St. Paul and Duluth Mining Company; St. Paul; $1,000,000; 100,000 shares; April 23, 1892. S. S. Smith, W. H. Squier, J. C. Southall, W. Ruan, W. P. Curtiss, R. H. Edwards, P. P. McVeigh, Jr.

Swan Lake Iron Mining Company of Minneapolis; Minneapolis; $1,000,000; 40,000 shares; April 4, 1892. G. H. Warren, W. G. La Rue, D. Waite.

Swedish American Iron Company; Duluth; $2,000,000; .20,000 shares; Feb. 23, 1892. C. A. Smith, O. N. Ostrum, N. O. Werner, J. Peterson, L. M. Erickson, A. Nelson, N. Hall, J. J. Eklund, N. A. Linderberg, J. A. Carlson.

Towanda Iron Company; Duluth; $3,000,000; 30,000 shares; March 2, 1892. J. T. Hale, B. T. Hale, J. Sullivan, R. H. Palmer, A. Merritt.

Twin City Iron Company; Duluth; $3,000,000; 30,000 shares; March 1, 1892. J. McKinley, A. E. Humphreys, G. E. Milligan.

Vermilion Iron and Land Company of Duluth; Duluth; $1,000,000; March 8, 1892. Changed name to **Kentucky Iron Company.**

Virginia Iron Company; Duluth; $3,000,000; 30,000 shares; March 1, 1892. J. McKinley, G. F. Piper, A. L. Warner.

Vulcan Iron Company; Duluth; $1,000,000; 100,000 shares; Feb. 29, 1892. F. Walker, A. H. Morris, M. A. Morris, C. O. Munns, R. H. Harris.

Wabigon Iron Company; Duluth; $50,000; 500 shares; Aug. 20, 1891. W. H. Fisher, D. H. Merritt, J. H. Upham, L. Merritt, W. A. Barr.

Wahkootah Iron Company; Duluth; $3,000,000; 30,000 shares; Mar. 14, 1892. L. Merritt, E. H. Hall, R. Jamison, J. Mather.

Washington Iron Company; Duluth; $3,000,000; 30,000 shares; Mar. 2, 1892. T. B. Mills, G. F. Piper, J. Spencer, R. A. Taussig, A. B. Upton, D. S. Culver, W. B. Welles, G. A. Leland, C. F. McComb, J. K. Redington, C. K. Lawrence, M. W. Bates.

Wenona Iron Company; Duluth; $50,000; 500 shares; Aug. 20, 1891. W. H. Fisher, D. H. Merritt, J. H. Upham, L. Merritt, W. A. Barr.

West Gogebic Iron Land Company; Minneapolis; $60,000; April 20, 1891. M. W. Lewis, J. A. Wolverton, F. B. Lewis.

Wyoming Iron Company; Duluth; $300,000; 3,000 shares; April 23, 1892. F. Cox, S. W. Eckman, W. F. Gore.

Youngstown Iron Company; Duluth; $3,000,000; 30,000 shares; March 1, 1892. A. Merritt, N. B. Merritt, A. L. Warner, C. C. Merritt, B. T. Hale.

Zenith Iron Company; Duluth; $2,500,000; 100,000 shares; March 28, 1892. G. F. Piper, H. H. Hanford, L. E. Judson, Jr.

Method and Cost of Mining on the Mesabi.

The excellent quality of the Mesabi ore and the large amount of it have been commented upon in the preceding pages. A few words as to the expense and probable method of extracting this ore from its bed and placing it on the cars ready for transportation to the furnace will be of interest. In an article in the Cleveland Iron Trade Review, July 21, 1892, the writer made the following statements:

"The most important feature of the Mesabi, in view of its distance from the furnace and forced competition with other ranges, is the cheapness of mining. A few estimates will make this clear. Old methods and old calculations will not answer on this range.

"Soft ore, large areas near the surface and horizontal deposits are not to be handled by deep shafts, air-compressors, timbering and costly pumps. It is the exception to find the ore covered by rock, and it is unusual to find more than fifty feet of glacial drift lying upon it. It is not to be supposed that there will be only a single method of mining here. Different men will have different ideas, and different properties will present different problems, but it is plain that the most of the mines will be worked as open pits, with the surface stripped off.

"Estimates of the cost of removing earth, sand, clay and gravel and boulders can be obtained from any railroad contractor. The estimated cost per cubic yard varies from six to forty cents according to the material and the facilities for removing it. With a railroad at hand a steam shovel will remove ordinary sand and gravel for six cents a yard. By hand work, without railroad facilities, it will cost from twenty-five to forty cents a yard.

"When the surface is stripped off, the ore is found in flat deposits covering twenty to sixty or more acres, and from twenty to ninety feet thick. Test pits are sunk in places one hundred and seventeen feet deep by pick and shovel, without a single drill hole or blast of powder. In other spots there may be twenty or thirty feet in a pit which is too hard to pick. This can be thrown down in large quantities when there is once a face on it, and can then be loaded by hand or steam shovel. Where no blasting is required, the expense of loading cars by hand labor will not exceed twenty-five cents per ton; by steam shovel it may reach ten cents. Where the ore is hard enough to blast, the expense of excavating and loading on cars may reach forty cents. It is not necessary to reckon into our calculation any interest on a large investment, for that is covered by royalty. No expensive plant is depreciating on our hands. Fewer damage suits arise from injuries received, because our men work by daylight.

"Let us now, with these figures before us, make a theoretical estimate of the cost of mining ore on almost any property on the Mesabi which has been developed enough to show the depth of ore and the amount of stripping. One cubic yard of ore weighs about two and one-half tons, one yard of earth about one ton. The average depth of ore so far revealed on several properties is seventy feet, and the surface thirty-five feet. In other places the ore is sixty or even eighty feet thick and the surface only twenty, but for the sake of estimation let us consider the ore only twice as thick as the surface. There are then two cubic yards of ore for each cubic yard of surface. But as each yard of ore weighs two and one-half tons there are five tons of ore for each yard of surface, and if the stripping costs the maximum of forty cents per yard the cost for each ton of ore is eight cents. At the minimum of six cents per yard for stripping, the stripping cost is only one and one-fifth cents for each ton of ore.

"When the surface is removed the ore is practically in a huge stockpile, containing in some instances several millions of tons. At the maximum cost of mining this by hand and in hard ore the cost of stripping and placing ore on cars is forty-eight cents per

ton. The minimum cost at the figures given above is eleven and one-fifth cents. The average is about twenty-nine and one half cents. But as there is more soft ore than hard the average may be expected to be about twenty-five cents. The cost of timbering alone in many mines on the south shore of lake Superior exceeds the total cost of mining millions of tons of ore on the Mesabi."

If the cost of mining is 25 cents the approximate cost of the ore delivered at Cleveland will be $3.10, distributed as follows:

Cost of mining, - - - - - -	$ .25
Royalty, - - - - - - - - -	.60
Railroad freight to the lake, - - - - -	.80
Lake freight to Cleveland, - - - - - -	1.20
Insurance, commission, etc., - - - - -	.25
	$3.10

These items will vary somewhat. The lake tariff at present is but $1.00 to Cleveland, and in some cases the last item will be only 15 cents. The royalty, too, will vary, and will average less than 60 cents. Different methods of mining will vary in expense. The above estimate is for mining by steam shovels and stripping off the surface. If the method of underground mining is adopted the cost will exceed the figure given above.

The average price for 60 per cent. bessemer ore is not far from $4.25 at Cleveland. If the large amount of Mesabi ore made suddenly available should force the price down to $3.75 per ton, there will still be a profit for the average Mesabi mine operator.

Quantity of Ore on the Mesabi.

How much ore is there on the new range? How long will it last? These are questions of importance and are frequently asked. The answer must be in the nature of an estimate at present. Different experts of equal skill would arrive at different results in an attempt to compute the ore in sight. Figures that represented anything like the truth, even though they were made by a competent and disinterested person, would be received with incredulity by those not familiar with the actual developments. Besides, there is no doubt that much more ore will yet be discovered; how much is merely a matter of speculation. Hardly a week passes now without the announcement of a new find, and new areas are continually being tested and found productive on the properties already under development. The Biwabik company has quite recently been presented with another mine on section 36, T. 56–18, by the good

judgment and industry of their explorer, Capt. J. G. Cohoe. The number of known merchantable deposits already exceeds twenty and many other promising localities have not yet been explored.

It is evident that there is ore in store for many years to come, and that permanent investments and improvements of the most extensive nature can safely be made, based on an expectation of the sufficiency and quality of this ore-supply. As already stated contracts have been made calling for the minimum production of one and a half million tons per annum. This is eighty per cent. more than has ever been produced by the Vermilion range in one season, and is about one-sixth of the entire lake Superior product. The yield of some of the largest mines, like the Mountain Iron, McKinley and Lake Superior, is not included in this minimum figure, nor are some others like the Canton, Kanawha and Great Western. It is moreover likely that some companies will ship more than their minimum amount. It may not be within the first two years, but after they are quite ready.

TRANSPORTATION.

Extensive railroad and vessel equipments are necessary for handling the product of an iron range. It seems rather questionable whether the railroads running to the Mesabi will be able to handle the ore which will be offered them in 1893. The iron mines are situated sixty to eighty miles from lake Superior. At the beginning of 1892 there was but one railroad, the Duluth and Iron Range, which crossed the Mesabi, and that was twelve miles from the nearest mine. The Duluth and Winnipeg, in running west from Duluth, formed an acute angle with the Iron Range and crossed it at Grand Rapids, on the Mississippi river. During the first nine months of this year, however, two roads were constructed and put in daily operation between Duluth and the new range.

The first road completed was the Duluth, Missabe and Northern. From the Duluth and Winnipeg, at Stony Brook, this road runs north over a level, drift-covered region for forty-two miles to the Mountain Iron mine. The road-bed is excellent, and curves and grades being few the operating expenses will be light. It was chiefly through the efforts of the late M. B. Harrison, Leonidas Merritt, K. D. Chase and Donald Grant that this road was built. It was put in operation during the first week in October. By its contracts with the owners and lessees of several of the largest mines this railroad is already assured of large business. A considerable number of ore-cars and heavy locomotives are now being constructed for this company.

The ore brought down over the Duluth, Missabe and Northern will be handled by the Duluth and Winnipeg between Stony Brook and the docks on Allouez bay. This road will also handle ore which will be delivered to them by other branch roads to be constructed farther west. One of these roads is now being built by the Swan River Logging Company from the crossing of Swan river to the mines in townships 57–22 and 58–20.

The Duluth and Iron Range branch to the Biwabik, Canton and other mines near the town of Merritt was also completed in October, 1892. In spite of many serious natural obstacles, such as heavy grades, this road has as fine a track and equipment and is as well managed as any road in the state. Its traffic is already large from the Vermilion range, and will manifestly be increased by the large output of the Mesabi. It is expected that both the Iron Range and Missabe and Northern will construct lines along the range connecting the various towns and mines.

For assistance in many ways, for valuable information and repeated courtesies, the officers of the geological survey are indebted to the Duluth and Iron Range, the St. Paul and Duluth, and the Duluth, Missabe and Northern railroad companies. The extension and successful operation of these roads, as well as others, is for the welfare and development of the wealth of the state, and they are factors perhaps second to none in forwarding its prosperity.

VALUE TO THE STATE.

The best gauge of a nation's commercial and political rank among the nations of the world is found in the record of its mining and manufacturing achievements. The country that makes the largest use of its natural products is the leader in all that constitutes national greatness. One good reason for the decadence of nations formerly foremost in the world and now of but little importance is the want of mineral resources or the ability to utilize them.

We may go farther and say that of all natural resources there is none which, properly developed and applied, confers such great riches and commercial importance on its possessor and user as ron. Gold and silver mines are valuable and their possession enriches nations as well as individuals, but "he who possesses iron will soon be master of the gold," and its benefits to civilization are greater and far more lasting.

Which are the leading countries in the world to-day? The United States and England are probably foremost in all that denotes prosperity and greatness. Which are the largest producers

and consumers of iron ore? The same two by long odds, having yielded together more than fifty per cent. of the world's output in the year 1889.

The same truth is borne out by a consideration of the different States of the United States. The four most populous and wealthy States in the Union are New York, Pennsylvania, Illinois and Ohio. In 1890 these four States ranked respectively fifth, first, fourth and third in the production of pig iron, having produced in the aggregate 73.5 per cent. of the entire yield of the United States. In the production of steel they ranked in the same order.

In Michigan, Wisconsin and Minnesota there was an average increase in population amounting to forty-one per cent. in the decade from 1880 to 1890. In these States the production of iron ore increased in a more than corresponding ratio. The average increase of Michigan and Wisconsin was 1210 per cent., while Minnesota, which did not appear as a producer in the tenth census, ranks *fifth* among the States in the eleventh. These commonwealths have not derived their full benefit from this large production of iron ore for two reasons. First, they have been producers but a few years. Second, their ore has been shipped away to be consumed in other regions; and it is not merely the production of iron ore, but the combined production and consumption or manufacture of iron that results in the greatest growth and prosperity.

With the exploitation of the mines on the Mesabi there will arise communities of inhabitants who will populate the northern portion of the state more rapidly than would be the case for almost any other reason. All the industries connected with mining and the support of a large number of people will be rapidly promoted. But the greatest good will come only from the establishment of furnaces to reduce the ore and factories to make finished articles for shipment to the western markets.

Minnesota has within her borders the greatest iron district known in the world to-day. It lies within her power to become the leading state in America. With these facts before them it is incumbent upon the citizens of this commonwealth to consider most seriously how to derive the greatest benefits from her mineral wealth. It is a sober fact that more merchantable iron ore is already known to exist on the Mesabi range than has been produced from all the other mines in the lake Superior region since they were first discovered. With this possibility of unprecedented prosperity and industrial growth every facility and inducement should be extended to those who may establish furnaces and factories within our boundaries.

Discoveries of ore on lands owned and leased by the State already promise an annual income of a quarter of a million, to be paid directly into the State treasury in the shape of royalties. The erection of blast furnaces to consume this ore would result in benefits to the state at large equal to several times the amount of these royalties. It might be a wise move on the part of the State to pay a bounty on each ton of ore reduced within her limits. If this bounty were simply enough to offset the royalty it would be a considerable inducement for the establishment of furnaces, and would be a paying investment for the State.

CLASSIFICATION OF THE THEORIES OF THE ORIGIN OF IRON ORES.‡

In discussing the various theories proposed for the origin of iron ores in Bulletin No. 6, the scheme or order adopted by Prof. A. A. Julien was followed. It has not proven entirely satisfactory, being often inconvenient and confusing. The following classification may be used in the study of the subject with a clearer understanding of the differences in the ideas entertained by geologists on this interesting question:

A. MECHANICAL.
- a. Extra-terrestrial or cosmical.
  - 1. Meteoric fall. [1.]†
- b. Terrestrial.
  - 1. Subterranean—eruption in dykes or accompanying basaltic flows. [2.]
  - 2. Superficial action.
    - *a.* Violent abrasion and transport. [13.]
    - *b.* Ordinary erosion. { 1. Concentration of iron sands. [14.] 2. Oceanic sedimentation. [8.]

B. CHEMICAL.
- a. Changes in situ.
  - 1. Change in the kind or quantity of iron already present in the rocks.
    - *a.* Alteration of diffused ferric oxide into ferrous carbonate. [10.
    - *b.* Metamorphism of bog ore. [11.]
    - *c.* Metamorphism of lake ore. [12.]
    - *d.* Alteration of ferrous carbonate or sulphide into ferric oxide. [8 in part.]
  - 2. Change in the kind or quantity of other minerals.
    - *a.* Substitution of iron oxide for some non-ferriferous mineral. [17.]
    - *b.* Concentration, by removal of other constituents. [4.] Similar to B a 1.

‡American Geologist, Nov., 1892, Vol. X., No. 5, p. 277.

†Figures in brackets refer to the theories as numbered and discussed in "The Iron Ores of Minnesota," Bulletin No. 6, Minn. Geol. Survey.

c. Electro-telluric action. [16.]

b. Removal by chemical action and subsequent deposition.

1. By action of heat—sublimation. [3.]

2. By action of water.

   a. In drainage basins.
      1. Oceanic precipitation. [8 in part.]
      2. a. Secondary product of the decomposition of basic rocks [18.]
         b. Secondary product from the decomposition of pyrite. [7.]

   b. In the rocks.
      1. Saturation of porous strata. [5.]
      2. Infiltration into cavities. [6, 15.]

   c. Deposit by springs. [9.]

COAL IN NORTHERN MINNESOTA.

During the past year there have been frequent reports of the discovery of coal in the region north of Duluth. The development of such extensive iron mines and the great desirability of coal deposits that can be used in connection with the iron has added to the interest with which such reports are usually received.

The opinion of the state geologist and the writer has been frequently expressed that the only coal of any sort in the northern part of the state is in thin seams of brown coal, occuring in Cretaceous shales, which were found in patches on the Little Fork river by the writer in 1888. This coal is not of good quality and the discovery of large amounts in thick beds would not be of such great importance as the newspapers would have us believe.

At the same time lignite is used to a considerable extent in treeless regions as fuel for ordinary heating and cooking purposes. In Texas and Dakota such coal is mined in considerable quantities. Grates of a particular pattern are devised in which to burn this coal and it plays quite an important part in the domestic economy of those regions. It is used in the form of briquettes in Germany. These briquettes are made by drying the brown coal until the water it contains is nearly all driven off and then subjecting a mass of it to a pressure of fifteen hundred to two thousand atmospheres. The resulting briquette is elliptical in form, about six inches long and one inch thick. It is so hard that it will not absorb moisture even though laid in water for some time. This coal is too fine-grained and not compact enough to use in blast furnace practice. If this brown coal should be found dehydrated and consolidated by heat or pressure consequent on eruptions or excessive faulting in the rocks, it would have a much

greater value. It is not impossible that such deposits may be found in some of the large areas northwest of Duluth as yet but little explored by the geological survey. It is quite desirable that some further examination be made of this region in connection with more thorough and careful mapping of the rocks of the Mesabi range. The value of good coal deposits cannot be overestimated, and if we have such in Minnesota the sooner we know it the better.

V.

SKETCH OF THE

Coastal Topography of the North Side

OF

LAKE SUPERIOR

With Special Reference to the Abandoned Strands

OF

LAKE WARREN

(The Greatest of the Late Quaternary Lakes of North America)

BY ANDREW C. LAWSON,

Associate Professor of Geology and Mineralogy in the University of California.

CONTENTS.

ILLUSTRATIONS.

INTRODUCTION.

The prosecution of geological investigations for the Geological Survey of Canada in the region northwest of lake Superior afforded the writer annual opportunities of obtaining cursory glimpses of the coast of the great inland sea itself, and on a few occasions of making a very limited reconnaissance of particular portions of it. He never, however, had the good fortune to be able to examine its geological features in detail. Those features, even to his limited acquaintance with them, appeared ever both grand and simple, and seemed to yield to mere inspection an exposition of the great principles of physical geology, which in force and clearness was second to none he had met with either in reading or in traveling.

Working gradually eastward, therefore, the writer had before him the prospect of some day entering upon the investigation of that interesting and rarely paralleled line of accessible rock exposure, the "north shore" of lake Superior, and of presenting a detailed account of the relations there revealed as a contribution to geological science. The severance of his connection with the Canadian survey in the spring of 1890 obscured this prospect, but the writer's thoughts still turned in that direction. In the following year after having settled at the University of California, it seemed to be advisable, before engaging in new investigations on the Pacific coast, to revisit lake Superior for the purpose of procuring information relative to some minor geological problems, which had been suggested to the writer in the course of such partial and unsatisfactory examinations as he had formerly been able to make. Among these problems was an inquiry into the character of the ancient shore lines of the lake. Stimulated by the interesting results obtained by Upham and Tyrrell in the lake Agassiz basin to the west and by Gilbert and Spencer in the lake Ontario (Iroquois) region to the east as to the deformation of ancient shore lines, the writer had been particularly attracted by the evidence of former high elevations of the lake; and had made some effort to gain definite information as to the distribution of terraces and beaches, and as to the probability of a detailed inquiry yielding sufficient data for purposes of generalization.

The interest and importance of such an inquiry lies, of course, in the evidence which it affords of local instability of the crust of the earth. On oceanic coast lines evidences of recent differential movements of the crust are ordinarily not difficult to observe. Such movements are not confined to the vicinity of these coasts but are probably common in the interior as well as on their periphery. But the evidence which makes this statement possible has until recent years been very meagre, and indeed, scarcely sufficient to satisfy the demands of exact knowledge. In the interior of the continents there is no absolute datum such as is offered by the surface of the ocean to which may be conveniently referred the altitudes of the land. There is not a set of agencies, such as the shore action of the sea, to score on the slopes a definite horizon that may be readily recognized as out of place when lifted beyond the reach of those agencies. The allied action of lake shores produces similar horizontal impressions, but the lake may go up or down with the portion of the continent in which it lies and otherwise share its movements, so that when such horizontal shore lines are seen high above the waters of a lake they are usually left there by the mere subsidence of the level of the lake. Thus there is no means of measuring the *absolute* vertical movement of any portion of the interior of a continent, except by the laborious and costly method of carrying lines of levels to the sea shore. But for the more immediate purposes of geological science the absolute measure of such movements is not needed. The science will be enriched in proportion as means are discovered recognizing the fact of recent *differential* vertical movements of the crust in regions remote from the sea and of affording some approximate measure of their extent without reference to any absolute datum. Such a means has been supplied by the modern study of the development of topographic forms, a study that, thanks to the masterly lines that have been laid down by Gilbert, Davis, McGee, Chamberlin and other leaders of the present time, bids fair to become one of the most important fields of research to engage the attention of the coming generation of American geologists.

As one result of such topographic studies it appears that in interior regions we may have good evidence both of the fact and of the measure of differential movements of the crust in (1), the character of stream erosion and deposition, and (2), the deformation of the abandoned shore lines of lakes. It is now generally recognized that streams are extremely sensitive to any change in the slope of their trenches or of any portions of them. There is a uniform minimum slope which they constantly seek to establish

and maintain. Any movement of the land leaves its record in a change in the intensity of the action of the stream, whether it be cutting or depositing; and in non-glaciated regions streams are now systematically inspected by geologists for the purpose of ascertaining whether the country traversed by them has been uplifted or depressed, or has maintained a fairly constant altitude. Evidence of this kind is, however, not always available.

The peculiar topography of certain regions is due to the fact of their having been occupied in comparatively recent times by lakes which have now wholly or partially disappeared. One of the characteristic features of such a topography is the presence of ancient shores of the lake at various altitudes on the slopes of the basin, marking as many stages of the water. These strand lines are often traceable as contours for hundreds of miles, and in some cases, as for example on lake Bonneville, the highest of such strand lines is a sharp demarkation between two classes of topography, the one that of the once submerged basin and the other that of the hills above the highest level of the lake. These strand lines were once of course horizontal. At the present day they are frequently found to vary from horizontality in a marked degree, and in this case they are said to have suffered deformation. This deformation affords us at once a proof and an approximate measure of the local differental movements of the crust. Among the most remarkable instances of such deformation of ancient shores are the cases of lakes Agassiz and Iroquois; the former a glacial or post-glacial extension of lake Winnepeg, and the latter a corresponding extension of lakes Ontario, Erie and Huron.

The ancient shore lines of lake Agassiz have been traced by Upham and Tyrrell on the front of the Pembina escarpment in practical continuity for many hundreds of miles on the open prairie, and are found to ascend to the northward at the rate of from six to sixteen inches to the mile.

The measurements of Gilbert and Spencer on the ancient strand lines of lake Iroquois show that they slope in a similar fashion. Thus there is very explicit evidence of the differential movement of the land surface of North America in two extensive regions lying on either side of the lake Superior basin. In view of this fact it becomes a matter of very considerable interest to ascertain what evidences the ancient strand lines of lake Superior afford of differental crustal movements. This was the motive of the present inquiry. The fact of the former high elevation of lake Superior has long been known, though not to the extent to which the writer is now able to establish.

Logan in his report of the geological survey of Canada, 1847, records the occurrence of terraces below the Petits Ecrits (Terrace bay) rising to an elevation of 331 feet above the lake. Terraces rising to nearly 100 feet on the south side of the lake were described and their significance appreciated in Foster and Whitney's "Report on the Geology and Topography of a portion of the Lake Superior Land District," Part I, 1850, and Agassiz in his "Lake Superior," 1850, discusses the terraces observed by him in his trip around the "north shore" and cites Logan's measurements.

But while the former high elevation of the lake was known, no effort whatever had been made to trace the strands around the coast and no suggestion had been offered as to whether they maintained their original horizontality or had been thrown into inclined attitudes. There was thus a serious gap in our knowledge which, it is hoped, will be in some measure filled by the information contained in this paper.

At the outset of the inquiry it was proposed simply to secure accurate data as to the altitude of the various strand lines at as many points as possible and to gather evidence which would help to trace particular strands around the coast. As soon as the work was begun, however, a comparison was naturally instituted between the characters of the present strand and those of the ancient and abandoned strands, the altitudes of which were sought.

This led to a consideration of the topography, not only of the immediate shore line, but also of the general coast of the north side of the lake. It was found that the coast presented very striking contrasts of topographical character which were due to marked differences in the petrographical and structural geology of its different portions. Thus, in the course of the search for elevated beaches and terraces, sufficient information was gained to serve for a general sketch of the topography of the north coast of the lake from Duluth to Sault Ste. Marie. The ancient strands of the lake are now simply topographic features which are, for the most part, displayed along the coast at no great distance from the shore. It seemed best, therefore, to include the discussion of these special features in a more general discussion of the topography of the coast. This discussion does not pretend to be in any sense exhaustive. It is a mere sketch which would be unwarranted were there any satisfactory account of the topography of the north side of lake Superior to be found in geological literature. Even as a sketch this description of the general topography of the coast suffers from the haste in which the work was done, the entire trip from Duluth to Sault Ste. Marie occupying only two months; and

also from the fact that the writer had no special qualifications for the work other than his general familiarity with the geology of a portion of the region. It is hoped, however, that the exact data which have been obtained regarding as many of the ancient strands of the lake as could be seen from off its present shore will compensate for what may be lacking in the general account of the coast; and that what is here set forth may be an incentive to others to make more detailed and therefore more valuable examinations of its various parts.

GEOLOGICAL PROVINCES FRONTING ON LAKE SUPERIOR.

There is a very evident relationship between the general topography of the north side of lake Superior and the geological conditions which obtain in different portions of its extent. Between Duluth and Sault Ste. Marie there are four great geological provinces fronting on the lake. These are the Keweenian, the Animikie, the Archæan and the Potsdam.

The Keweenian occupies the entire Minnesota coast from Duluth to Grand Portage. Beyond this point the various formations of the Keweenian are probably geologically continuous around the whole of the north shore, but the out-crop of the rocks is mostly confined to the islands which fringe the coast and to the peninsulas terminating in Thunder cape and Magnet point, which are here regarded as part of the island fringe rather than of the main land. A few outlying patches are also found at different points on the main shore, but these are quite limited in extent except in the vicinity of Nipigon, where a neck of these formations connects the lake Superior Keweenian basin with the extensive interior Keweenian basin of lake Nipigon.

The Animikie rocks occupy the main shore of the lake uninterruptedly from Grand Portage to Port Arthur and also the chain of islands which stretches from Pigeon point to Thunder cape. From Port Arthur onward to the meridian of the Slate islands the Animikie formations are geologically continuous, but are much interrupted along the shore by projecting areas of the underlying Archæan, and, on the peninsulas between Thunder bay and Nipigon bay, by overlying sheets of the Keweenian.

The Archæan shares the coast line with the Animikie and Keweenian from the vicinity of Port Arthur to the eastern end of Nipigon bay. Beyond Nipigon bay as far as the outlet of the lake the coast yields to the rugged dominion of the Archæan; the only

exceptions being the Keweenian outliers of Gargantua and Mamainse and the flat-lying patches of Potsdam in the vicinity of Goulai's bay and Sault Ste. Marie.

These Potsdam formations constitute the fourth geological province; and, although its extent on the lake shore is very limited, the rocks composing it have an extensive distribution as is shown by their presence on several of the larger islands off this part of the coast, and much of the character of the southeasterly part of the lake is due to their presence. The Potsdam sandstones are also of peculiar interest, inasmuch as they form the dam in the St. Mary's river which holds the waters of the lake at their present level;—a dam which has evidently only recently been rendered functional by the lowering of the waters of lake Huron below the level once occupied in common by that lake and lake Superior.

Corresponding to each of these great geological provinces, there is a distinct type of coastal topography. And here it may be well to draw a distinction between those elements of the topography, which from Gilbert's classic work have come to be regarded as the "topographic features of lake shores" and what may more comprehensively be designated the *coastal topography*. On any rocky coast line of a lake there may be developed certain topographic elements, the perfection of form of which may be evolved practically independently of the varying character of the geological conditions of the coast. Of these topographic elements we have beaches, bars, spits, terraces, sea-cliffs, caves, pot holes, etc. These are the direct product of wave action along the shore and may be common to all lakes. They will therefore be referred to briefly as the "shore features." The term "coastal topography" embraces these and also those features which, though not necessarily developed by shore action, are well displayed along the coast line and are of a local character and peculiar to any given lake or to several lakes existing under similar geological and physiographic conditions.

Just what should be comprised under the designation "coast" is somewhat difficult of definition. That there is, however, a definite belt of the land extending back from the shore to a varying extent, which is commonly recognized as the coast, goes without saying. The area recognized by the U. S. coast and geodetic survey as the "coast" appears to be that portion of the land visible from a ship sailing within easy distance of the shore. It may also be generally described as the more or less rudely beveled edge of a continental tract where it breaks away in altitude to form the margin of a topographic basin occupied by water.

The coastal topography, then, of lake Superior, as thus understood, is determined in each geological province by the conditions peculiar to that province. Even the common "shore features," such as beaches and wave built terraces, although found in equal perfection of form in different provinces, are clearly affected by the geological conditions, and their development is not always simply a question of a given amount of wind and water and time. The material of which they are constructed is, for example, largely extra-lacustrine in its derivation. The waves supply themselves often with but a subordinate proportion of the materials which they employ in the construction of topographic forms, particularly along the front of the Archæan province. The great bulk of the material is brought down by stream action and sub-aerial agencies. The abundance of this material and, therefore, the number and aggregate extent of beaches, bars, spits and terraces, varies directly with the character of the rocks and with the presence or absence of morainic accumulations.

The depth of water and the angle of the sub-aqueous slope also are conditions which materially affect the development of such structures, and both of these conditions vary with the geological character of the shore. It will thus be found that the "shore features" proper vary as to their abundance and extent according to the readiness with which the rocks of any given province yield the materials for construction, and according as the sub-aqueous slope is favorable or the reverse. Other conditions are the character of the streams entering the lake and the time during which the lake has remained at the same level. The latter is, however, a condition which is a constant quantity for all parts of the shore of the lake. But these "shore features" proper are but small and subordinate elements of the sum total of the coastal topography of the north shore of lake Superior.

A very important feature of the topography, and one strictly dependent upon the character of the rocks, is the shore contour or the line of intersection of the coastal slope and the surface of the water. This embraces both the general form of the lake or the trend of its shores, and the sinuosities and indentations subordinate to that general trend. The general trend of the north shore of lake Superior, although a dominant element of the topography, has practically no relation to littoral forces; and even the detailed forms and minor sinuosities of the contour are ascribable on these rocky coasts only in part to differential erosion, a major portion representing simply a horizontal section through pre-existing forms.

Another feature of scarcely less prominence on the coast is that which becomes apparent in longitudinal profiles along the mean local trend of the shore. Such profiles indicate the hight and boldness of the promontories, headlands and minor projections of the coast. The breadth of such features is also shown, but this dimension is better read off from the shore contour where the variation is apparent. The character of the profile may, like the details of the shore contour, be due either to differential shore erosion or to the submergence of pre-lacustrine forms. On lake Superior these profiles are for the most part vertical sections of partially submerged forms which antedate the lake, and their aspect is peculiar to each of the geological provinces.

Still another feature of the coastal topography, and the most important for the purposes of an inquiry into ancient shore lines, is that which is best represented by series of profiles transverse to the shore. It is that element of the topography which is dependent upon the hight of the land in the vicinity of the shore contours and upon the shoreward slope, which slope may be modified by the presence of shore features developed at levels of the lake now abandoned. For very considerable stretches of the coast, however, these modifying features are absent, the bald rocky slopes having retained no impression of former occupation by the waters of the lake; and in this case the transverse profile is practically independent of littoral action. In order to make clear to what extent these various elements of the coastal topography are dependent upon the conditions peculiar to each geological province, it will be necessary to review briefly the structure of the entire coast.

GEOLOGICAL AND PHYSIOGRAPHIC CONDITIONS PECULIAR TO EACH PROVINCE.

The Keweenian from Duluth to Grand Portage consists essentially of a well stratified series of volcanic flows, having a gentle, but very constant, lakeward dip, which does not exceed as a general rule ten degrees. The sedimentary formations are represented also in the series, but only to a very limited extent, and occupy less than one-half per cent. of the coast line between the points above mentioned.

The pre-Keweenian surface upon which the series rests is exposed at a number of points on the shore, but its exposure at any one place is comparatively small. The rocks of which it is composed are massive, coarse-grained, granular aggregates of

labradorite *and are similar to rocks which are well known in the Archæan. They are doubtless Archæan inliers within the Keweenian province, and they exhibit all the evidences of profound erosion and rounding which the Archæan shows at other points on lake Superior where overlapped by the Keweenian.

Since the time of their outflow over this surface of presumably Archæan rocks, the Keweenian strata have not suffered any disturbance sufficient to fold or even to tilt them to any noteworthy extent. The prevaling lakeward dip at low angles is probably partly due to the altitude of the slope over which the lavas flowed, rather than entirely to a differential movement of once horizontal strata.

But, while the Keweenian formations have remained almost exempt from disturbances of this kind, they have been profoundly affected in another way, and the geological structure is more complex than might be inferred from the simple statement of the composition of the series as above given.

The series has been invaded by very many later intrusive masses, which appear along the line of the present coast either as dykes, or, more commonly, as injected sills; while there are also not a few masses of igneous rocks which, considering the very limited study that has been given to the geology of the coast, it would be rash to place definitely either with the regular bedded constituents of the series or with the later masses which cut it, although they doubtless belong to one or the other of these categories. The dykes usually do not vary much from the vertical, and the intrusive sills coincide with the planes of stratification of the bedded flows.

Very large portions of the rocks of the Keweenian series are vesicular or amygdaloidal in character, and many, particularly those of an acid composition in which the vesicular structure is not as well developed as in the more basic flows, are traversed by irregular joints to so remarkable a degree that it is scarcely possible to secure the smallest hand specimen the form of which is not conditioned by joint planes.

There appears to be no great contrast in hardness or in power of resisting disintegration between the Keweenian strata and the intrusive masses which cut them. The basic intrusives afford evidence, however, of being more decomposable and the acid masses

*These rocks, here styled Archæan, are in the horizon of the gabbro and its associated crystallines, included by the Wisconsin and Minnesota geologists in the base of the Keweenian; although. by the Canadian geologists, generally considered "Laurentian." See A. A. A. Sci., Boston, 1880, p. 425, and ninth Ann. Rep., Geol. and Nat. Hist. Survey Minn., p. 387. [N. H. W.]

of being less so, than the bedded rocks. Faults which can be clearly recognized as such are not prominent, although certain blocks of strata with precipitous fronts and gently sloping backs, which are observable some miles inland in the vicinity of Poplar river, suggest the presence of faults with oragraphic tilting. It is not improbable, moreover, that the entire Minnesota shore with its persistent line of cliffs follows the line of a fault scarp. The intrusive sills usually appear at an altitude which is about the present level of the lake or but slightly above it.

To these broad geological features there remains to be added a statement of three important physiographic facts in order to have before us the salient conditions which have controlled the development of the peculiar topography of the Minnesota coast. The first of these is that, if we except the drainage of the St. Louis river, the hydrographic area of Minnesota which is tributary to lake Superior is a comparatively narrow strip parallel to the shore of the lake, the water shed being a high ridge not many miles inland. As a consequence of this the streams flowing into the lake, although all rapid, and though actively deepening their trenches, are insignificant in size and bring but a small amount of material to the shore. The second physiographic condition alluded to is the rapid deepening of the water off the Minnesota coast.

The third condition is the exposure of the shore to the open expanse of the lake without the protection of any material breakwaters.

The Animikie rocks are geologically older than the Keweenian and underlie them. The emergence of the Animikie from beneath the Keweenian may be easily observed in the vicinity of Grand Portage as has been well described by Irving. The lower series presents several striking contrasts with the higher, the most important of which is due to the diverse character of the rocks. While the Keweenian is made up almost entirely of volcanic flows, the Animikie is composed altogether of sedimentary strata with no trace of contemporaneous volcanic formations. The series consists essentially of uniformily fine grained gray sandstones which locally are quartzytes, black more or less carbonaceous shales or slates, certain cherts and jaspers, beds of carbonate of iron, hematite and magnetite, a very sparing proportion of conglomerate, and occasional lenses of non-ferruginous carbonate in the slates. These rocks occur in strata which, except in local instances, as in the town of Port Arthur and near Gunflint lake, have been dis turbed very little from the horizontal, the average dip of the strata

being in a southeasterly direction at angles probably not exceeding five degrees; and they are frequently quite flat or very gently undulating. The rocks of the entire series, with the exception of certain of the cherts, the carbonates and the hematites and magnetites, which together form but a small proportion of the total volume, are characterized by a strongly pronounced shaly or slaty structure, the cleavage of which is parallel to the planes of bedding. This fissile character of the rocks renders them liable to rapid erosion. Were they not protected in a peculiar way little of them would have remained to the present time, and instead of forming parts of the highest and boldest cliffs on the lake they would long ago have been planed down to flat shelving forms, few of which would remain above the surface of the water. The protection which has so effectually, over large areas, enabled these rocks to withstand the active disintegration to which they are subjected, is afforded by the later intrusive masses which have invaded the series. These intrusive rocks are all basic in composition and are of the character of diabases and gabbros. They appear in the series in two distinct ways: (1) as intrusive sills or sheets lying horizontal or parallel to the stratification and resembling contemporaneous beds, for which they have by earlier observers been mistaken; (2) as vertical dykes. Some of the dykes have been observed in continuity with the sills and evidently represent the canals by which the material for the sills came up from deep sources. The most of them, however, are of later origin than the sills and intersect the latter.

The dykes have two chief trends, viz: N. E. and S. W. for the larger and more important, and about N. W. and S. E. for the smaller and less numerous dykes.

The dykes are very abundant in the vicinity of Pigeon river, and for some few miles northeast along the Canadian coast and on the islands as far as Pie island, constituting the dominent structural feature. From McKellar's point on to McKay's Mt., however, the dykes are not so prevalent and the horizontal sills have been the controlling factor in the development of the topography. These sills have very commonly a thickness of about 100 feet and in places reach 400 feet. Their altitude in the vertical column of strata varies from a position at the water's edge to elevations of over 1,000 feet, and ordinarily their position is several hundred feet above the lake.

Both dykes and sills have usually a distinct columnar structure, the columns in the former case being horizontal and in the latter vertical. This structure, of course, facilitates disintegration, but

these intrusive rocks, notwithstanding this feature, are either in the form of sills or of dykes, prominently harder and more durable than the shaly strata which they penetrate.

Faulting is much more clearly recognizable in the Animikie province than in the Keweenian and is a common occurrence, many scarps being due primarily to this cause.

In this physiography the front of the Animikie province between Grand Portage and Thunder bay presents as interesting contrasts as does the geological structure. There are two considerable streams flowing into the lake over these rocks, viz: the Pigeon and the Kaministiquia, besides some minor brooks. The Pigeon contributes very little to the shore drift since its sediment is largely intercepted by lakes. The Kaministiquia has on the other hand brought down much sediment which has served for the construction of very important features. The divide is much farther removed from the lake than in Minnesota. The water off shore is also much shallower as a rule than on the Minnesota coast and there is frequently a shelving bottom. Added to this shoal water condition is the presence of a chain of islands, which form a very effectual breakwater and protect the shore from the violent action of the open lake.

The Archæan forms the basement upon which the Animikie rests in glaring unconformity. The actual superposition of the Animikie upon the well eroded Archæan surface may be observed at several points, with the Keweenian lying flat on the former. Very frequently, however, the Animikie is absent and the Keweenian is imposed directly upon the Archæan. But, whether the Archæan emerges from beneath the Animikie or the Keweenian, the contrast which its rocks present to the formations of either of the latter series is equally profound. The petrographical character and general structure of the Archæan is so different from that presented by the newer rocks which rest upon it, that comparisons on parallel lines of observation are difficult to make. Antitheses of conditions meet one at every point of view, and the topographic forms evolved under these conditions, save those due solely to wave action, present correspondingly marked contrasts.

The Archæan complex of this coast is readily resolvable into two broad divisions: (1), a great volume of profoundly altered sedimentary and volcanic rocks, characteristically schistose or in the form of massive greenstones, which have suffered intense disturbance and which correspond to what has been designated the Ontarian system*, and (2), immense batholites of irruptive gneiss

*Bull. Geol. Soc. Am., Vol. I, pp. 175-194.

and granite, which have invaded the rocks of the Ontarian system from below in the most irregular fashion, corresponding to that division of the Archæan which is commonly recognized as Laurentian. These Laurentian rocks exhibit only to a very subordinate extent those evidences of disturbances and deformation which are so abundantly apparent in the schists which they have invaded. The Laurentian gneisses and granites occupy much more of the shore than do the metamorphic and schistose rocks of the Ontarian; and each of these divisions of the Archæan province has its own peculiar phases of a topography of a general type. The entire surface of this province presents a remarkably hummocky or mammilated aspect due to pre-Paleozoic erosion* modified by the glacial action of the Pleistocene.† The rocks are fresh and free from the mantle of rotten rock arising from secular decay which covers similar crystalline rocks in some regions. The granites and gneisses, being in this fresh condition at their surface, practically homogeneous, remarkably free from divisional planes due to pressure and movement, and having prelacustrine hummocky or rounded forms which are least affected by erosive agencies, condition a topography which to a very large extent is independent of shore action. Where cut terraces are present on the coastal slopes of these rocks they have usually been carved out of morainic material or notched in the face of embankments formed early in the history of the lake. These embankments are rarely sufficiently continuous to obscure the broad aspects of the rocky slope. The schistose and greenstone rocks of the Ontarian traverse the region in curvilinear belts or zones, separating neighboring Laurentian batholites. These belts sometimes emerge on the coast in the form of great ridges, the extremities of which form promontories. They condition a much more jagged and linear aspect of topography; and along the present shore, at least, the rocks of which they are composed yield to the cutting action of the waves much more readily than do the granites and gneisses. Sometimes the trend of the coast coincides with the strike of these belts for a distance, when precipitous cliffs face the lake, which, however, are not necessarily sea-cliffs. The essentially Archæan conditions of this province are modified somewhat by a great system of diabase dykes which traverse the region and which were noted by Agassiz‡; they coincide remarkably closely with the trend of the coast. This coincidence of coastal trend is best seen between Nipigon and Peninsula.

*i. e. Pre-Algonkian. (Algonkian = Animikie + Keweenian.)
†Bull. Geol. Soc. Am., Vol. I, pp. 163-174.
‡Lake Superior, its physical character. etc., 1850.

Between Peninsula and Otter head the dykes are very numerous and only a portion of them coincide with the general trend of the coast. The majority cut the line of the coast obliquely. Between Otter head and Michipicoten harbor the dykes are both parallel and transverse to the trend of the coast, there being apparently two distinct systems of fissures. The dykes do not as a rule exceed one hundred feet in width and are vertical or nearly so. When occurring in the Laurentian and where degradation has proceeded more rapidly than the country rock, a distinct trench marks their occurrence. When they traverse the Ontarian rocks they are less recognizable and less important topographically, their color being more nearly that of the country rock and their susceptibility to degradation not markedly different. Whether these lines of dykes are also fault lines has not been clearly made out. It is impossible, as has been suggested, that their origin is associated to some degree with the depression which gave rise to the lake Superior syncline.*

There is much morainic drift scattered over the coast of the lake, chiefly in the form of boulders. There are also protecting distinct morainic accumulations, although the form of these moraines is difficult to recognize on account of the timber and also from their having been modified by shore action at various stages of the lake and degraded by stream action. There are numerous streams entering the lake along the front of the Archæan province. Most of these are, however, small and the watershed is not far distant from the coast. The entire coast is well exposed to southerly and westerly storms.

The rocks of the Potsdam province are undisturbed, flat, or nearly flat, shaly sandstones, generally of a red color. These sandstones extend out from the base of the Archæan hills, which they encircle in a level plain. They have not been observed on the north side of the lake at elevations exceeding fifty feet above its level. These rocks appear to occupy an extensive tract beneath the waters of the lake in its southeastern portion. Whether on the islands or on the main land these rocks, by their petrographical uniformity, their stratigraphical simplicity and the proximity of their summits to the local base level of erosion, condition a simple and mature topography. The coast along which they are found is mostly protected from the full sweep of the lake in storms, and the water off shore is comparatively shallow.

*Lake Superior, its physical characters, etc., 1850.

SHORE FEATURES OF THE PRESENT STRAND.

It has been stated at the beginning of this paper that there is a very evident relationship between the coastal topography of the north side of lake Superior and the geological conditions which obtain in the various provinces which have been outlined as fronting on the lake. The shore features of the present strand constitute an important element of the general topography of the coast, and the relationship alluded to becomes very apparent in a consideration of some of these features. It is here proposed to sketch very briefly the character of the leading shore features and to compare those pertaining to the different provinces with one another, having reference chiefly to the geological conditions which have controlled the development of the shore..

SEA CLIFFS.

Among the most striking of the shore features which engage the attention on the Minnesota coast are the lines of the low sea-cliffs, which rise abruptly from the water, ranging in elevation from a very few feet in some places up to as much as 210 feet of vertical precipice at the Palisades. These cliffs are remarkable for their great continuity, their general uniform hight and for the general scarcity of shore drift along their base. The most striking feature of the shore coutour,—viz: its simple unbroken trend,—is also a character of the cliffs and must necessarily be taken into account in a description of them. These cliffs are *seemingly* the direct product of shore action and appear from their abruptness to be in active recession; yet they are not receding altogether by reason of the process of battering and undermining to which the recession of cliffs is usually ascribable. The products of the mechanical disintegration of the cliffs do not as a rule lodge at the base of the cliff and become the tools for the further cutting of its base. Wherever such detritus lodges and is handled by the waves as a battery there is usually a little notch or vertical gash established in the cliff wall. As a rule, moreover, it is to be noted that the cliffs, independently of any softening or rounding of their brink by atmospheric agencies, are not strictly precipitous except where the rock of which they are composed is uniform from top to bottom. On the contrary, although the general effect is that of precipitous cliffs, the base is nearly always more projecting than the higher portions and the cliff rises in a series of rude steps, the front of each step being usually nearly vertical, while its surface slopes gently lakeward. The explanation of this character

of cliff lies in the nature of the rocks and their structural features. As has been stated, the rocks of the coast, with some local exceptions, are volcanic flows, frequently of no great thickness, associated with which are sheets, probably injected as sills, and a few dykes. The volcanic rocks are very commonly, when basic, vesicular or amygdoloidal and, when acid, are of the nature of a dense red porphyry which disintegrates mechanically with the greatest readiness. These bedded and regularly stratified volcanic rocks have a constant lakeward dip along the whole coast, the inclination usually not exceeding ten degrees. It is these petrograpical and structural features which seem to be the real conditioning causes in the development of this remarkable line of cliffs in so far as it is actually receding, and the shore action a minor and, as it were, the determining or precipitating cause of the degradation. The bedding planes, the intricate jointage, the columnar structure of some of the beds, the porous character of many others, and lastly, the lakeward dip, all favor the loosening and dislodgement of blocks under the influence of an abundant supply of water by the waves and the changing temperature of the climate; and so the cliff recedes, being only to a limited extent worn down by the battery process. But the total recession has been very small as is evidenced by the fact that for many parts of the shore only a very narrow subaqueous shelf, disproportionate to the size of the cliff, has been formed, or none at all. And indeed there are grave doubts, amounting almost to certainty, that, although this line of precipice is now functionally a sea-cliff of the present strand, it is not primarily and genetically a sea-cliff. The way in which the cliff rises from deep water as the upward continuation of a very pronounced subaqueous cliff [See Pl. XI, Fig. 1.] indicates very clearly that its origin is essentially pre-lacustrine or at least extra-lacustrine; and the suggestion can scarcely be resisted that primarily the cliff of the Minnesota coast is a great fault scarp. Two facts may be cited which harmonize with this suggestion. (1) The trend of the coast is in direct line with the great linear series of dykes which extends from Pigeon point to Thompson island, and which probably is continuous with the similar series of dykes having the same trend on the islands and points on the south side of Thunder cape. (2) Mr. Peter McKellar has informed the writer that a great fault is observable near the head of Thunder bay in the line of the east side of the bay, and that the cliff which forms this side of the bay is without doubt a great fault scarp. This scarp would parallel the one suggested as determining the line of the present Minnesota shore, or converge upon it very obliquely.

FIG 1. NATURAL ARCHWAY AT POINT OF GREAT PALISADES. ILLUSTRATING CLIFF WITH BASE BELOW WATER LEVEL. (PP. 198 AND 214.)

FIG. 2. SCENE AT OTTER COVE, NORTH SHORE OF LAKE SUPERIOR

Along the front of the Animikie province true sea-cliffs are not prominent or common features of the present strand. There are, indeed, numerous precipices rising from the water, but they are not all sea-cliffs in the strict sense of the term. Two types of these coastal precipices may be mentioned: (1) where the rock of the shore is that of one of the great trap dykes which intersect portions of the coast, particularly in its southwestern portion; and (2) where the thick sheets of columnar trap, which have been intruded between the nearly flat Animikie beds, descend by a gentle local dip to the water's edge. In both of these cases precipices are formed, those of the columnar flat sheets being more nearly vertical than those of the dykes. But in neither case, so far as the observation of the writer goes, are these cliffs ever functional as sea-cliffs in the sense that they are receding by reason of wave action and have a wave cut terrace at their base. Usually they rise from deep water and have no shelf at the water line. Their origin as topographic forms long antedates the lake and is ascribable to the process of erosion, which, in conjunction with orographic movements, is responsible for the basin in which the lake lies. There is, however, a type of precipice which is in its functional relations to the present strand, a true sea-cliff, although, as seems probable in the case of the Minnesota shore, the locus of the cliff was determined by other agencies than shore action. The cliff referred to is best seen on the east side of Thunder bay, above Sawyer's bay. Here the shore is at the base of a long uniform line of vertical cliff which is in active recession and which has a boulder-strewn, sub-aqueous shelf at its base. Here the face of the cliff is composed of horizontal Animikie slate, which yields readily to the battery which plays on its lower part during westerly storms. The recession is so active that it is encroaching upon a terrace of a higher stage of the lake where a similar cliff has been developed. The initiation of this line of cliff, now a sea-cliff, is, in the opinion of Mr. McKellar, expressed in conversation with the writer, due to a fault, the displacement of which is apparent near the head of Thunder bay. But these rocky precipices, whether sea-cliffs or not, do not form any very extensive portion of the shore of the Animikie province. By far the greater part of the shore is along the talus slopes of the magnificent cliffs of differential degradation, which surround the Thunder bay district and have made its topography famous. On these talus slopes earlier shores have in places constructed embankments. But, whether the present strand lies along the primary talus or along these secondary em-

bankments, there has been no important cutting of sea-cliffs. There are a few minor instances where the shore has eaten back somewhat and given rise to a small cliff.

Along the front of the delta of the Kaministiquia there is a low but abrupt rise above the shore which is also to be interpreted as a sea-cliff. A low cliff of a very few feet encircles some of the islands, such as Flatland island, which have a small altitude above the lake in consequence of the absence of protecting dykes or sheets of trap to restrain the slates from yielding rapidly to erosion. Some of the small islets of Thunder bay also may be but the remnants of larger islands truncated at the shore line by the process of cliff-making.

Along the strand of the Archæan province rocky declivities are an almost constant feature of the shore. The coast is bold, bare and rugged; but true sea-cliffs are remarkably scarce. The rocky slopes descend to the water with usually no break in the profile and most frequently with no embankment of shore drift or appearance of shelf at their base, except in the bays where sea-cliffs in rock are not ordinarily developed on any shore. Where the shore is occupied by the Laurentian gneiss and granite practically no incision has been made in the face of the rocks at the shore line,and the surface of rock which plunges beneath the waters of the lake has with little or no qualification the precise form and slope which it had, when, earlier in the history of the lake, it was covered by several hundred feet of water, and which it had, indeed, before the existence of the lake. The entire coast has been glaciated and the glacial markings, grooves and hollows are frequently seen to pass down beneath the water's edge without an abrasion to dim their sharpness. The hummocky, rounded forms of rock which are so well displayed on many parts of the coast are the same which are found throughout the region far removed from shore action; and many of the slopes which descend to the water, whether steeply precipitous, or gently inclined or rounded in hummock form, may be indisputably recognized as precisely the slopes upon which Animikie or Keweenian sediments were deposited or over which the Keweenian lavas flowed. The basin of lake Superior is very ancient, more ancient than some glacialists have dreamed of in their philosophy. It is perhaps hardly necessary to go into the causes of this scarcity of sea-cliffs on a coast where one would at first thought expect to find them abundant, but the chief of these may be enumerated as follows: (1). The obdurate, tough and resistant character of the rocks which prevents their yielding

shore drift for battering purposes. (2). The steepness of the original slope of the coast and the consequent depth of water near shore, which prevents the lodging of such shore drift as is available and hinders the building up of embankments which would facilitate the transport of shore drift to where it could be effectively used by the waves. (3). The shortness of the time at which the shore has been at its present level. Given time sufficient and the two other adverse causes would be overcome and we should have sea-cliffs around the entire coast. Where the shore lies along the schistose rocks of the Ontarian system of the Archæan, such sweeping statements as to the absence of sea-cliffs cannot be made. These rocks have certainly yielded appreciably to the cutting action of the shore and the original profiles of the prelacustrine forms have been notched. But the shore notch is not heavy and the recession of the fresh cliffs has usually been so slight as to modify the original profile but little, and the steep slope to the water which these schistose rocks commonly present is essentially that of the pre-lacustrine form. These cliffs in the schistose rocks may be best seen along the shore east of Otter head. On this coast, also, to the east of Dog river, may be observed a very interesting instance of the active formation of sea-cliffs in soft material, by the waves cutting into the shore embankments which have been built up at higher stages of the lake. The cliff of the present shore has been receding so rapidly that a portion of a terrace 16 feet above the level of the lake has been entirely undermined and obliterated back to and beyond its own original sea-cliff, affording a very clear picture of how gaps in the series of ancient shore lines may occur. [See Fig. 15, in descriptive notes under Dog river.]

On the shore of the Potsdam province the sea-cliff which commonly separates the shore from the plain formed by the upper surface of the flat sandstones is frequently worn down and is not always a prominent feature of the shore. It probably tends to recede more rapidly by atmospheric and organic degradation in many portions of its extent than by the attack of shore forces, so that its edge or brink is rounded and softened and the lakeward slope of the cliff is rather low. It is not precipitous on the islands.

BEACHES, BARS, SPITS, ETC.

Boulder, pebble and shingle beaches are common features of the north shore of lake Superior, and some of these are of magnificent proportions as regards their cross profile. They are all, however, limited in their horizontal extent, except in the Potsdam province,

to the pronounced indentation of the shore line. They are least abundant in the Keweenian province and most abundant in the Animikie. In the Archæan province they are only of local occurrence chiefly in the vicinity of the mouths of streams, there being extensive portions of the shore along the front of this province which yield no shore drift for the formation of such embankments. The shore of the Potsdam province presents either a continuous beach or a boulder strewn shore, but, as the Potsdam rocks are of very limited occurrence on the north side of the lake, the extent of these simple beach or bouldery strands is even here small when compared with the total length of the shore.

The extensive lines of cliffs along the shore of the Keweenian province on the Minnesota coast would seem to presuppose the occurrence of more extensive beach accumulations than are actually found; the simplicity of the shore contour, however, and its remarkable freedom from indentations in which the shore drift could lodge, militate against the development of beach embankments. The shelving character of the rocks with their constant lakeward dip, and the depth of water immediately off shore, are also effective causes in preventing accumulations of shore drift except in the most favored localities. Such localities are not wanting along the coast of Minnesota, and a few of these may be referred to.

The finest of all the lake Superior beaches is of course the bar which spans the head of the lake from Duluth to Superior City. This is so well known already that nothing more than a mere mention of it is here required. Beyond Duluth the first important beach is that which forms the bar across the mouth of the Knife river. The river has at its mouth developed a small delta in the shelter of a low point of rock. This delta material is chiefly sand, but there is mixed with it drift from the shore to the eastward. This accumulation has extended outward till it is now even with the protecting rocky point, and here it is probably stationary, having ceased its lakeward expansion by reason of the surplus being carried beyond the point. The front of this delta extends as a well defined bar almost entirely across the mouth of the stream and the waves have banked it up in the form of a broad beach.

The shore of Agate bay and that of the adjoining Burlington bay has a beach embankment of considerable extent, the pebbles being mostly of local derivation. Among these, however, were found two fragments of cream colored limestone containing fragments of fossils indicating that some of the beach material is derived from morainic accumulations.

FIG 1. GRAND MARAIS. FROM TWO HUNDRED FOOT BLUFF WEST OF THE HARBOR. (PP. 203, 246.)

Gooseberry river discharges into a small bay which is somewhat protected by a jutting point of rock, and the shore in the vicinity of the stream presents a finely built beach of small uniform gravel of a red acid volcanic rock, which occurs in the neighborhood and which is easily broken down into small fragments without undergoing chemical decay or losing its hardness. The mouth of Split-rock river is similarly protected by Split-rock point and a beach shuts off from the lake the marshy flood plain of the stream.

The mouth of Beaver river is also well protected by a point of rock and between the stream and Beaver bay there has been thrown out a spit composed almost entirely of sand brought down by the stream. The spit is parallel to the stream and is only a few hundred yards long. The waves have built it up into a broad low arched beach. The river side of the spit is being constantly corroded by the stream and the material thus worn down is carried into the bay where it is added to the outer or lakeward side, where by the action of the wind and waves it is soon carried again over to the river side, again to be undermined by the stream. Thus there is a constant undermining on one side and up-building on the other side of the spit, while in position it remains constant. [See Pl. xii, Fig. 2.]

Between the Palisades and the mouth of Baptism river a beach of greater length than is usual on this shore has been thrown across an embankment. The material is chiefly derived from the cliffs of the vicinity, supplemented by gravel from the Baptism river, the rock there being the same red porphyry which supplies so much of the gravel of the shore drift.

At Good Harbor bay some soft sedimentary shales protected on the lakeward side by a ridge of hard igneous rock have afforded conditions favorable for shore erosion, and the bay is the result. The cliffs at the back of the bay, being of this soft shale in nearly horizontal attitudes, are actively receding and a shingle beach has been piled up along the base of the material which has not yet been reduced to clay and carried out to deep water. The beach is not large and in violent storms is doubtless entirely moved. A few miles farther on Grand Marais harbor presents a fine pebble and shingle beach which extends in the form of a broad based spit connecting the island on which the lighthouse stands with the main shore. [See Pl. xii, Fig. 1.] The material of this beach is again the same red quartz porphyry which has been so often referred to as a source of supply of shore drift. The cliff from which it is in this case derived is a little to the east of Grand Marais.

Fish-hook point, the mouth of Brule river, and Deronda bay are the only other places along the Keweenian of the Minnesota shore where notable beaches occur, and in all these cases they are found in the immediate vicinity of cliffs of red quartz porphyry and the embankments are nearly altogether composed of this material.

These beaches thus briefly alluded to are the only very prominent ones that attract attention in coasting along the shore from Duluth to Grand Portage. The longest of them is probably not more than one-eighth of a mile in length; and, if it is borne in mind that these are distributed over a shore of nearly 150 miles, their mere enumeration is sufficient to indicate the meagerness of beaches along its extent. It is not intended by this explicit allusion to these beaches to imply that there are not others. There are many small coves along the shore, so small that they afford no shelter for a row-boat, and also short stretches of open shore between jutting points, where local detritus has accumulated and has been thrown up into beach form. The proportion of these, however, to the total length of coast is very small. There are also stretches of shore which are essentially bare shelving rock, but which in patches are encumbered with boulders. In general the impression received by inspection of the Keweenian shore from a row-boat is that of a wonderful dearth of shore drift and a great extent of bare rock, and one is constantly struck by the association of the more important beach accumulations with the occurrence of a red quartz porphyry and an allied and quite similar rock in which quartz can not be detected macroscopically. This association depends upon the property which this rock has of yielding pebbles by reason of its shattered jointage structure, the resulting fragments being hard and resistant.

In passing from the Keweenian to the Animikie province along the shore of the lake one is impressed by the great contrast which is presented in the relative abundance of beaches. Along the Animikie shore beaches are the rule except where the great dykes occupy the water's edge. The reason for the difference lies in the diverse petrographical characters of the two formations. In the Keweenian the only rock capable of yielding shore drift in abundance, the red porpyrhy, is of limited occurrence, and it is prevented from yielding large quantities by its association with harder rocks which keep the line of the shore from receding. In the Animikie province it is far otherwise. The Animikie slates and slaty sandstones and quartzytes occur along the entire Animikie coast and have yielded an overwhelming amount of material eminently suitable for the formation of shingle beaches. As has been already

pointed out the topography of the Animikie coast varies according as the igneous rocks which invade the slates are prevailingly dykes or prevailingly horizontal sheets or sills. At the southwestern part of the Animikie coast, in the vicinity of Pigeon river, the dykes prevail and the country is intersected by a great plexus of immense dykes, with limited patches of slates in horizontal attitudes lying between. This condition obtains also on the islands which stretch from Victoria light to, but not including, Pie island. In the portion of the coast thus affected, the dykes usually extend lakeward and as bold promontories marking off well defined bays; and the water being deep off the extremity of these promontories, the beaches are confined to the bays, so that there is not a long continuous beach on this part of the coast, although the various individual beaches in the bays are of considerable extent. Where the sides of the dykes occupy the shore, as on the north side of Pigeon point, Victoria island and Thompson island, the water is usually deep, and there is no shore drift nor beach accumulation, the cliffs (pre-lacustrine) rising precipitously from the depths of the lake. Passing into that portion of the Animikie coast where trap sills prevail and the dykes play only a very subordinate role or are absent, we find practically continuous beaches interrupted occasionally by precipitous headlands. This feature of the shore is associated with an almost entire absence of sea-cliffs. This statement may be surprising to readers familiar with the famous Thunder bay landscape with its beetling cliffs. The vertical precipices of Thunder bay overlooking the lake are not sea-cliffs of the present shore. They are primarily cliffs of differential degradation of pre-lacustrine origin, and the topographic masses which they limit are true mesas. At some of the higher stages of the lake they have been functional as sea-cliffs, but at present the subsidence of the lake has brought the shore in most cases low down on their talus slopes, and the cliffs have returned to their former condition of cliffs of differential degradation. As an exception to this last statement may be mentioned the cliffs which occupy the shore immediately to the northeast of Little Trout bay, where the main trap sheet or cap descends below the level of the lake, and its edge rises vertically 100 feet or more above the water, and there is no beach or visible talus. From these statements it will be apparent that, although beaches abound on the Animikie shore, the material of which they are composed is not derived immediately from neighboring sea-cliffs. It comes entirely from the old talus of the cliffs not now affected by shore action and much of it has come from earlier beach embankments higher up on the same talus slope.

Thus in our comparison of the Keweenian and Animikie shores we arrive at the seemingly paradoxical statement that along the former, although there are extensive lines of functionally active sea-cliffs, there is a scarcity of beaches; while along the latter, although there are practically no sea-cliffs shedding fresh detritus, shingle beaches abound.

Intermingled with the local drift of the beaches of the Animikie province there are, it should be mentioned, numerous boulders of glacial derivation. There are also many more or less angular boulders of trap from sills and dykes, and some parts of the shore are thickly strewn with such boulders to the exclusion of the ordinary pebbles and shingle.

A general statement respecting the distribution of beaches along the shore of the Archæan province is difficult to formulate. Beaches are common, but they are due to local causes and are not uniformly distributed. The intricate indentation of the coast affords everywhere ample opportunities for the lodging of shore drift and the piling of it up into beach embankments, but the supply of shore drift is very small. Where the Laurentian granite and gneisses occupy the coast shore action has been impotent both at the present and all earlier stages of the lake to affect the sculpture of sea-cliffs, which would supply the drift necessary for the accumulation of important lines of beach embankments. The schistose rocks of the Ontarian system have been more yielding, but still supply a comparatively small proportion of the shore drift. The petrography and structure of the province preclude the possibility of cliffs of differential degradation having at any previous period in the history of the region afforded a supply of talus material which might be seized by the waves and wrought up into embankments. This poverty of general shore drift and the prevalent separation of the bays by bold headlands, preventing the drift of one bay from passing around into its neighbors,conditions a shore whose beaches are dependent upon local and extra lacustrine sources of supply. These sources are chiefly two, viz: (1) stream deltas, and (2) glacial drift; and both of these are variable. The result is that the shore is a long succession of small bays, some of which have beaches and some of which have not. In the vicinity of the streams, deltas have been developed usually of small size consisting chiefly of stream pebbles, and these afford material for beaches as described in the reference to wave-built terraces. Where there are no streams the beaches, when present, consist chiefly of erratic boulders with but a sparing proportion of smaller pebbles and gravel. Thus a very small proportion of the beach

material of the Archæan province is of local origin. One other source of beach material on this part of the shore remains to be mentioned. At higher levels of the lake, the streams, not having well-defined trenches of their own cutting, but following the depressions between the hummocks and hills of this mammillated region, emerged on the coast in some cases at places more or less distant from their present point of discharge, and the embankments which accumulated at these old outlets have been cut into by lower stages of the lake and the whole or part of their material carried down to lower portions of the rocky slope; and some of it enters into the composition of the modern beaches. Even when the point of discharge has not materially changed, the shore contour at higher stages was in certain other cases such that the stream detritus brought down to the lake was much more extensively distributed than at the present stage. So that not a little of the pebbly material which enters into the composition of the modern beaches is derived from the streams of the neighborhood, although this is not apparent at the first glance.

Of the beaches of the Potsdam province little remains to be said. The rocks of the Potsdam are uniformly flat, or nearly flat, often shaly sandstones; and the effect of wave action upon such rocks has been the development of a uniform and continuous shelf which is coextensive with the occupancy of the shore by these rocks, and which is now frequently occupied at the shore by a low beach. The profile of the beach of course varies according as it is sheltered or is exposed to an open expanse of water. The water off these shores is generally shallow, and wave action therefore feeble on the immediate shore, so that high beaches do not prevail. Scarps or cliffs of importance are not common, although a few good sea-cliffs occur, especially on the islands. An occasional abrupt rise of the ground may perhaps be interpreted as a cliff, genetically considered, but the rocks seem to yield readily to the degrading influence of the weather and vegetation. The shallow off shore water and the shore itself is frequently strewn with boulders which the waves are unable to handle. These boulder strewn shores are regarded as a phase of beach. Under other condidions, which would allow the access of more potent waves to the shore, these boulders would undoubtedly be ridged up together in beach fashion. The sweeping contour of the shore, the low, continuous beaches and the degradation of the cliffs, all give the shore, as has been said, an aspect of great maturity.

DELTAS AND WAVE-BUILT TERRACES.

On the north shore of lake Superior deltas and wave-built terraces are naturally associated. The *sine qua non* of a wave-built terrace is the accession to the shore of more detritus than the forces of the shore can either transport or pulverize. On a shore where the development of cliffs has not proceeded sufficiently to yield an abundance of detritus, the only place where such a congestion of shore drift is liable to occur is in the vicinity of streams which are bringing down pebbles and boulders to the lake and there dropping them to build up a delta. Thus it happens that along the present strand of lake Superior, where the sea-cliffs are not largely developed, the chief wave-built terraces are found on the outer margins of the deltas of certain streams which are transporting coarse material, and in the vicinity of certain rocks of limited distribution which disintegrate rapidly and shed an abudance of hard fragments, as in the case of the red porphyry rocks of the Minnesota coast. Streams which are transporting sediment in a fine state of division are also forming deltas at the lake shore, but there are no wave-built terraces associated with them. Of these the delta of the Kaministiquia is the most notable. Other streams which emerge on the open coast where the water is deep close to shore are also building up deltas, but these are entirely sub-aqueous or are barely perceptible. Still other streams have their sediments intercepted by small lakes before reaching lake Superior, and these add little or nothing to the shore drift. The fewness of the deltas and wave-built terraces on the north shore renders it difficult to compare the local influences which have controlled the development of these features in the different geological provinces. There are certain general considerations, however, which may be mentioned. The extreme meagreness of the visible delta accumulations along the shore of the Keweenian province is doubtless due to the proximity of the Minnesota water-shed to the coast and the consequent smallness of the streams, and to the exceptional depth of water close to the shore line. The scarcity of wave-built terraces, which are independent of deltas, is to be ascribed to the simplicity of the shore line, which does not favor the lodging of shore drift, and to the fact that the extensive cliffs which characterize the Minnesota shore are only effective sea-cliffs to a limited extent, being probably conditioned by a pre-lacustrine structural feature.

Along the front of the Animikie province there are only two streams of importance, the Pigeon and the Kaministiquia; and of these the former appears to be a very young stream, while the latter is probably one of the oldest streams associated with the pres-

ent physiography of the lake Superior basin. The one stream has a small and insignificant delta, while that of the other is large and important, as is noted more in detail below. The sediment carried by both streams is fine, and there is no wave-built terrace associated with their deltas.

The scarcity of wave-built terraces, which are strictly ascribable to the present strand of the Animikie province, is not due to any lack of shore drift, but rather to the following fact: The more recent stages of the lake have had their shores along talus slopes or earlier shore embankments, and the general shore contour for very considerable stretches has not materially changed, although the lake has subsided through many successive stages. Thus there has been opportunity afforded for such a distribution of the shore drift to be effected as to establish a practical equilibrium without tendency to transport so long as no new accessions are made to the shore; and we have seen in our discussion of the cliffs, that for the greater part of these shores the amount of shore drift is now constant, or is diminishing slowly by pulverization. In the process of establishing this approximate equilibrium, much of the shore drift has gathered inthe bays and has been ridged up into parallel beaches; but as this has proceeded *pari passu* with the lowering of the level of the lake, the ridged terrace which has resulted differs from a simple wave-built terrace in the fact that it is not level, but *slopes*, the more lakeward ridges being lower as a rule than those farther from the lake. The additions to this sloping wave-built terrace made by the present stage of the lake are not important and usually do not exceed one or two beaches.

The delta-building streams of the Archæan province seem for the most part to draw their detritus from the earlier formed embankments of the lake, through which they have cut their way; and these embankments would seem primarily to have been built up of material derived from morainic accumulations, as true sea-cliffs supplying shore drift have never at any stage of the lake been prominent features of the shore. No well characterized wave-built terraces, dissociated from deltas, have been observed along the shore of the Archæan province. In the Potsdam province there are no deltas; and no wave-built terraces were observed, although it is possible that they may be found in the bays which were not examined. Their existence is, however, improbable. A few notes are here given on the more important deltas and wave-built terraces of the north shore, based not on a careful study of their features, but only on such cursory examination as the time devoted to the work would allow.

The Delta of the Kaministiquia.—The largest and most impressive delta of the north side of lake Superior, as well as the most accessible for study, is that of the Kaministiquia river. The lower portion of the stream for many miles back from its mouth has cut its trench down into the delta, which has been accumulating throughout the higher stages of the lake, and this trench is continued into the lake as a sub-aqueous channel, navigable for large lake craft, through the delta now accumulating out to deep water. The river has three mouths, known as Fort William river, McKeller's river and Mission river. These embrace two islands of the older delta, the river bifurcating twice in the vicinity of the town of Fort William, about three miles from the lake shore. The material brought down by the stream is all fine, and appears to consist of clay and light sand; and this has been true far back in the history of the delta, as appears from an inspection of its structure as revealed in the trench walls of the river. This section shows uniformly for many miles from the mouth a lower portion of an indefinite thickness of blue clay, over which is spread a continuous sheet of sand which forms the surface of the ground. The blue clay has a minimum thickness at a distance of fourteen miles from the shore of probably fifty feet. The sand is not quite uniform in thickness and ordinary sections show that it ranges from two to ten feet. This structure in two strata, or two sets of strata, the material in each being quite different from that in the other, becomes easily comprehensible when we consider the two main conditions attending the development of the delta, viz: (1) The extension of the delta embankment from shallow into deep water—a condition common to all deltas; and (2) the subsidence of the base-level of erosion as the level of the lake dropped, which would cause a more rapid lakeward extension of the delta than if the base-level were constant. Of the two classes of material brought down by the stream the clay would be carried out to deep water, while the sand would be dropped in shallow water. But the shallow water at any given stage of the lake, except the highest, was deep water for the preceding stages, so that the sand for this stage would be spread out over a clay bottom. The same process would of course operate with a constant base-level, but the horizontal extension of the delta would not be nearly as rapid. The process is in operation in the growth of the delta of the present shore. The shoals from the mouth of the river on either side of the channel out to the vicinity of the Welcome islands, are sandy and have a very gentle slope, so that a sailboat may ground half a mile from shore, within hailing distance of a two thousand-ton

propeller steaming up the channel, as the writer has experienced. Near the Welcome islands the slope becomes steeper and out beyond the islands is clay bottom. Thus the development of the present delta is but a continuation of the same growth which has built up the great delta extending far up the valley of the Kaministiquia. At the apex of the delta, near Kaministiquia station, its structure is different, as is indicated elsewhere; but here the condititions were different, the current was powerful and coarse material was handled by the stream. The channel of the stream near the lake is so open and unobstructed that the older portion of the delta, back of the present shore, is not subject to serious overflow, and only the subaqueous portion is growing. The slope of the older delta surface is, as it should be, away from the banks of the stream, at least on the north side towards Port Arthur. The south side of the stream has not been examined. At the line of the present shore the delta is faintly terraced by the development of a low sea-cliff, as if marking a distinct drop of the surface of the lake of a few feet.

On the surface of the subaqeous delta is an exceptionally shoal linear area between the shore and Mutton island, so that it is scarcely possible for even a row boat to pass between. This linear shoal appears to be the direct product of wave action, and the final result will doubtless be a bar connecting the island with the shore.

The Delta of the Mazokamah.—At the mouth of the Mazokamah river a delta of stream gravel is at present being built up. The river is a small, rapid stream issuing directly upon the lake through a narrow cañon. The latter is a sharp V-shaped cleft in the high rocky bluffs which here front the lake. On the west side the flat-lying Keweenian rises in vertical walls, and the face of the heavy sheet of columnar trap which rests upon it frowns down on the shore from an elevation of 1,000 feet or more. On the east side the Archæan rises in scarcely less formidable hills with varying slopes and much greater complexity of form. Since the removal of the ice sheet the Keweenian cliffs have been receding, while the Archæan hills have not been sensibly modified by the agencies of erosion. Although the stream is rapid, and is lowering its trench like all streams entering the present level of lake Superior, the bulk of the material which it brings to the shore is derived from a great embankment of beach gravel which has been thrown part way across the cañon at the higher stages of the lake, and which the stream is now undermining. The slides from the cut through this embankment tend to choke the stream, and it is the purging

of the channel of this slide material which supplies nearly all of the pebbles for the delta now under construction. The delta which is thus accumulating on the exposed shore of Nipigon bay is not a simple delta; for the storms have given its surface, on its outer part at least, the ridged character of a wave-built terrace; and the structure throughout, as far back as the waves originally reached, is doubless a composite of that of a simple delta and a wave-built terrace, the latter being gradually dissected and overwhelmed as the delta extended lakeward. To the northwest the delta passes into a true wave-built terrace beyond the reach of the delta overflow. The entire embankment has a width from the original shore of from one-eighth to one-quarter of a mile, and is over a mile in léngth, extending to Mazokamah point. It has a fairly uniform level, except near the mouth of the stream, of from three to six feet above the lake.

The Delta of Nipigon River.—The Nipigon is the largest stream flowing into lake Superior, yet its present delta is small and unimportant as a feature of the present strand. We have not far to look for the reason of this. The stream itself is the drainage of a large lake and just before it drops into lake Superior it expands into a series of small lakes, so that the sediment which it carries over the rapids at Nipigon bridge is exceedingly small in amount, and the water appears to be perfectly colorless. Just below the rapids, however, the eddy of the stream is undermining a high embankment of sand and gravel and this affords sufficient material for the silting up of the small bay or inlet of Nipigon bay which forms the last couple of miles of the stream's course.

The Delta of Gravel River.—The Gravel river is bringing to the north shore of Nipigon bay a copious supply of gravel and the accumulation of this makes the delta of the stream a prominent feature of the present shore. The area of the delta which lies out beyond the general line of the shore is probably about a mile square. It is dissected by the stream and has a uniformly level apperance, any slope that it may have being exceedingly gentle. The surface of the delta, like that of the Mazokamah has the characteristic parallel ridge structure of the wave-built terrace, and the recent formation of the outermost of these ridges is very apparent.

The Deltas of the Michipicoten and Pic Rivers.—At the mouth of the Michipicoten there is an extensive delta accumulating resembling somewhat in its mode of development that of the Kaministiquia. The portion of the delta which is accessory to the present strand is due to the continuation of the processes which have been

in operation through several higher stages of the lake. At the front of the delta successive beaches have been thrown up and in turn have been cut through by the stream. There is a similar delta at the mouth of the Pic river associated with which is a long sand beach of the present shore. Neither of these deltas was examined sufficiently carefully to warrant any farther statement regarding them. They would, however, doubtless well repay careful study.

The Delta of Brulé River.—The embayment of the coast into which the Brulé river discharges is filled with a great wave-built terrace, the material of which is partly a delta accumulation of the stream and partly due to the lodging of shore drift shed from the neighboring cliffs to the south. These cliffs and the rocks through which the stream is cutting are largely acid volcanic rocks of the nature of quartz-porphyries, easily susceptible of mechanical disintegration. As they have accumulated the fragments have been from time to time thrown up into storm beaches one in front of another till the embayment has been filled out nearly even with the general trend of the shore. It is one of the few cases of simplification of shore line by filling in on the Minnesota coast.

Wave-Built Terrace at Grand Marais.—The small wave-built terrace at the harbor of Grand Marais is the only one of note on the north shore of lake Superior which is not dependent upon a stream for its supply of beach material. A short distance to the northeast of the harbor is a sea-cliff of quartz-porphyry which is shedding angular fragments of rock from its face very rapidly. The cliff is vertical, and has receded between prominent points of more resistant rock till a distinct bay has been formed. At higher stages of the lake there has been a similar supply of the same material, though not all from the same cliff. The detritus thus accumulated has lodged at Grand Marais, and the formation of the harbor at that point is due to the extension lakeward of this embankment in the form of successive storm beaches, till the latter joined with the rocky island shore on which the lighthouse stands. This junction was effected by the running out of a spit from the shore till it met the island. The construction of the wave-built terrace was begun at somewhat higher stages of the lake than the present, and is doubtless still in progress, but the growth is on one side only of the original spit, there being no new supply of beach material within the harbor.

MINOR FEATURES OF THE NORTH SHORE.

There remain to be noted as minor features of the north shore the forms known as *stacks, caves, clefts* and *pot-holes*, and these can be disposed of in a word. These features have been found

only along the shore of the Keweenian province, and in all cases to a very limited extent and of exceptional occurrence. Stacks are only found where a portion of the shore, usually not more than a few hundred yards, is occupied by exceptionally soft material that is yielding rapidly to shore erosion to form a small bay or cove. The best and most characteristic stacks were observed between Baptism river and the Saw-teeth, where the rocks occupying adjoining portions of the shore are of very diverse character as regards their hardness and coherence.

Small caves a very few feet in diameter are found in the face of some of the cliffs. These are above the water line, and are not developed by the battery of shore drift against the face of the cliff, as there is no shore drift in sight; but are evidently caused primarily by some local weakness of the rock which enables simple wave action, assisted by the solvent power of the water, to wear out the cavities. Ordinary over-arched shore caves due to the battering of shore drift against the base of the cliffs are not found along the Minnesota coast, except at the Palisades, where some fine ones have been formed; and here the battering process is a small factor as compared with simple wave action acting on the infinitely jointed porphyry of the cliffs. These caves form magnificent archways, through which one may pass in a large row-boat with ease. [See Pl. XI., Fig. 1.] Ordinarily, however, the cliffs are so low that the incision made at their base is, owing to bedding and jointing planes, carried to the summit, and a distinct Λ-shaped cleft in the face of the cliff is the result. These clefts are numerous along the Minnesota shore, and there may be seen almost invariably lying on their sloping bottom the boulders and pebbles with which their sculpture is effected. There is a fine arch on the north side of Pigeon point wrought out of coarse gabbro.

Pot-holes are not commonly developed on lake shores. They are usually the products of stream action. On one part of the Minnesota shore, however, they are distinctly the product of wave action, and may be observed in process of formation. The place where they were observed is on the shore about two miles east of the mouth of the Temperance river. Here the shore is occupied by an amygdaloidal lava of uneven texture, which forms a shelving lakeward sloping platform. In this platform are numerous pot-holes, the deepest having a depth of about four feet and a diameter at the mouth of about three feet. In the bottom of the pot, unless it is very shallow or has been breached, there are always one or more hard erratic boulders, which do the work of grinding out the hole when set in motion by the waves pouring over the surface of the

platform. The holes are not as symmetrical as hose formed by stream action, but there is no essential difference between them and the latter. It is to be noted that the rocks which are here susceptible of having pot-holes developed in them by wave action also afford in the canon of the Temperance river the finest, though not the largest, pot-holes to be seen in any of the streams of this coast. The canon of the river is formed by a systematic series of deep pot-holes which have breached into one another, giving the walls of the canon a concavely scalloped form.

Similar shore pot-holes are referred to by Agassiz as occurring at cape Choyye.

COASTAL CONTOURS.

THE PRESENT SHORE CONTOUR.

Of the various elements of a coastal topography the shore contour is the most constant and therefore perhaps the most essential and important. Other topographic elements may shrink into comparative insignificance and some of them may vanish entirely or may never be developed, but the shore line is always present. Like some other phenomena that belong to the category of the "ever present" it is apt to be overlooked among the factors in the total effect which constitutes the topography of a coast. The variation in the character of a shore line is a variation in quantity—in the length of the line. In quality it is practically unvarying, there being no attributes of excellence or imperfection by which we can qualify a description of it. Its shape or form of curve may be regarded roughly as a function of its length, being simple or intricate in proportion to the extent of time which traverses a circle of a given diameter and passes through to the center. The inconstancy of direction of the shore renders the possible variation of the form of the contour practically infinite. Thus the most constant feature of a coastal topography may be the most inconstant in form. But notwithstanding this variability there is usually a certain broad character peculiar to the contour of any shore developed under uniform geological conditions which, though difficult of precise description, may be distinguished readily from that of an adjoining shore developed under different geological conditions. This statement would probably be difficult to substantiate in the case of very mature shores, but it is probably only in exceptional cases where the shore of a large lake is uniformly mature, and the degree of maturity is largely dependent upon geological conditions.

When we consider the form of the shore contour of the north side of lake Superior in its relation to our four geological provinces, we are at once struck by the pronounced character peculiar to each province. In none of the other topographic features of the coast is there a more definite and unmistakable dependence upon strictly geological conditions. The moment we pass from one province to another so soon do we pass from one kind of shore contour to another. This contrast of the character of the shore contour can best be appreciated by an inspection of a map of the lake. But as maps of lake Superior on a suitable scale for such a comparison are not common, certain portions of the shore are here reproduced to illustrate the character of this feature in the different provinces. [See Figs. 1, 2 and 3.] And here it is well to recall the fact that the *apparent* simplicity of a shore line as interpreted from a map is in a measure dependent upon the scale of the map. Of the two shores both mapped as simple lines one may be serrate in minute detail while the other may be quite as simple as represented.

Shore Contour of the Keweenian Province.—The shore contour of the Minnesota coast from Duluth to Grand Portage is on the whole a remarkably simple line. It has the form of a slack bow concave to the lake. Projecting headlands and deep bays are entirely absent. Such salients and re-entrants as are worthy of note are obtuse in form and do not appreciably add to the length of the shore line. Yet in minute detail the line is frequently sharply jagged and serrate; and there is a marked absence of those sweeping sinuous curves which characterize mature shores. Shore erosion is active in the production of coves and the whole tendency of development appears to be, in this adolescent stage of the shore, the reverse of simplification. The present stage of the lake found the shore without indentations and a vigorous beginning has been made in the work of evolving them and in effecting a more intricate form of shore contour. But it is scarcely more than a beginning. The notches, clefts, and coves of the shore can only be rendered appreciable on a very large scale map and do not affect the general statement of the simplicity of the shore line considered as a whole. The shore contour of the Keweenian in the vicinity of Black bay and between that and Nipigon bay is very different from that of the Minnesota coast, and the reasons for the difference are not fully understood as the Canadian distribution of the Keweenian has not been carefully examined. This much is known, however, that in the latter district the shore contour is intricate, and is further complicated by the presence of great numbers of islands lying off shore in a fairly well defined belt. The

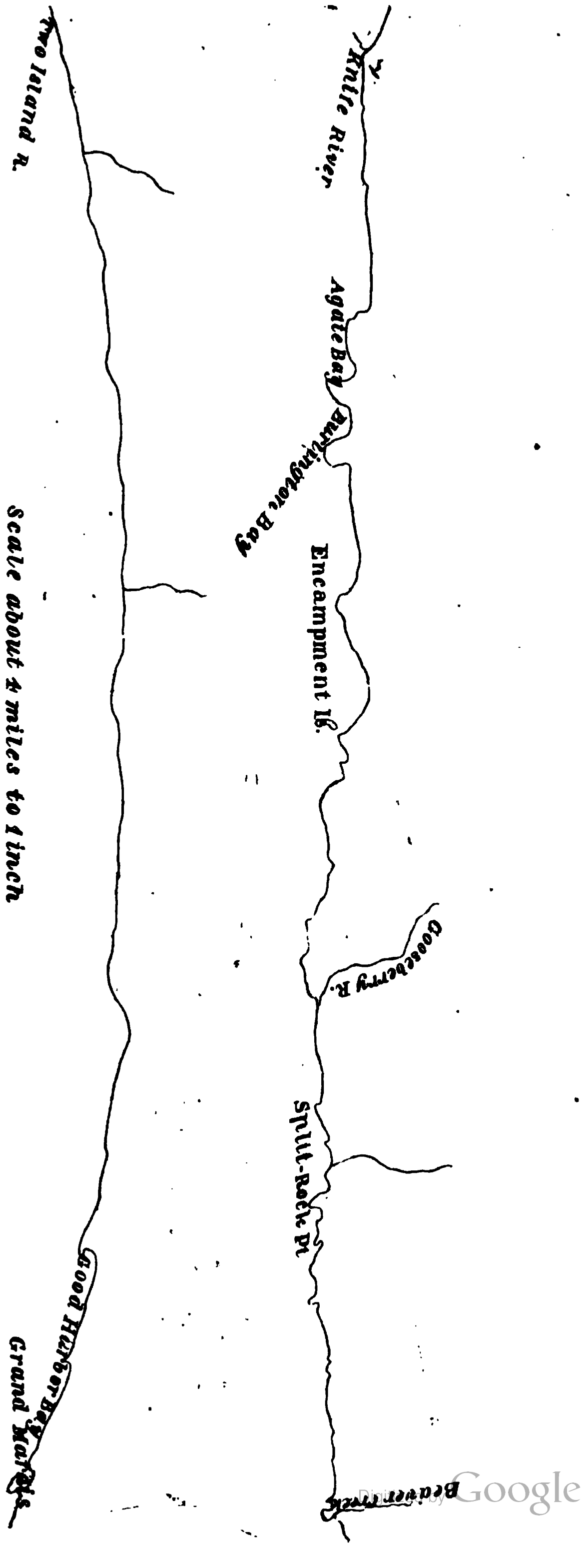


Fig. 1. Examples of the most complex and the simplest shore contours of the Keewenian Province along the Minnesota Coast.

Fig. 2. Shore contour of the Animikie Province. Scale four miles to an inch.

conditions differ from those on the Minnesota coast in the presence of a greater mixture of clastic rocks among the volcanic and in the greater abundance of dykes. These differences do not seem, however, to fully account for the great contrast in the topography of the two Keweenian areas; and the suggestion is strengthened, that the simplicity of the Minnesota coast is due to the fact that primarily it is a fault scarp.

Shore Contour of the Animikie Province.—The general trend of the shore along the front of the Animikie province is not a simple line. Deep narrow bays and prominent sharp headlands prevail, and the length of the shore line is large in proportion to the extent of the coast. The sculpture which gave rise to these bays and points is pre-lacustrine and the tendency of the shore action is, in contrast to that noted on the shore of the Keweenian province, towards simplification. The tendency in this direction is, however, not strongly marked on account of the resistant character of the extremities of the promontories which have not yet been appreciably truncated at the line of the present stage of the lake. See Fig. 2. The tendency is chiefly manifest in the filling up of the heads of the bays. While the shore contour of the Animikie province is in strong contrast to that of the Keweenian by reason of these large salients and re-entrants there is also a radical difference in the minute detail of the shore contour in the intervals between the points and along those portions of the shore which are exempt from bays. There is very little of the sharp local notching and clefting of the shore line where the shore is rocky and none of it where the shore is occupied by shingle. Thus the shore contour of the Animikie province is intricate in its general features but simple in its minute details; while that of the Keweenian is simple in its general features and serrate in its minute detail. The conditions governing the local trend of the bays and points along the Animikie front is easily recognizable and there is a prevailing parallelism in these features.

Shore Contour of the Archæan Province.—The shore contour of the Archæan province is exceedingly intricate in detail. If the shore were represented on a map of a scale sufficiently small to obliterate the detail, so that it would express merely the mean trend of the coast, it would be indicated by a fairly simple, obtusely zigzag line extending from Nipigon to Sault Ste. Marie. In this general and varying trend there may be recognized two degrees of detail: (1) Wide-mouthed bays and broad or obtusely rounded headlands which indent the mean trend of the shore to the extent

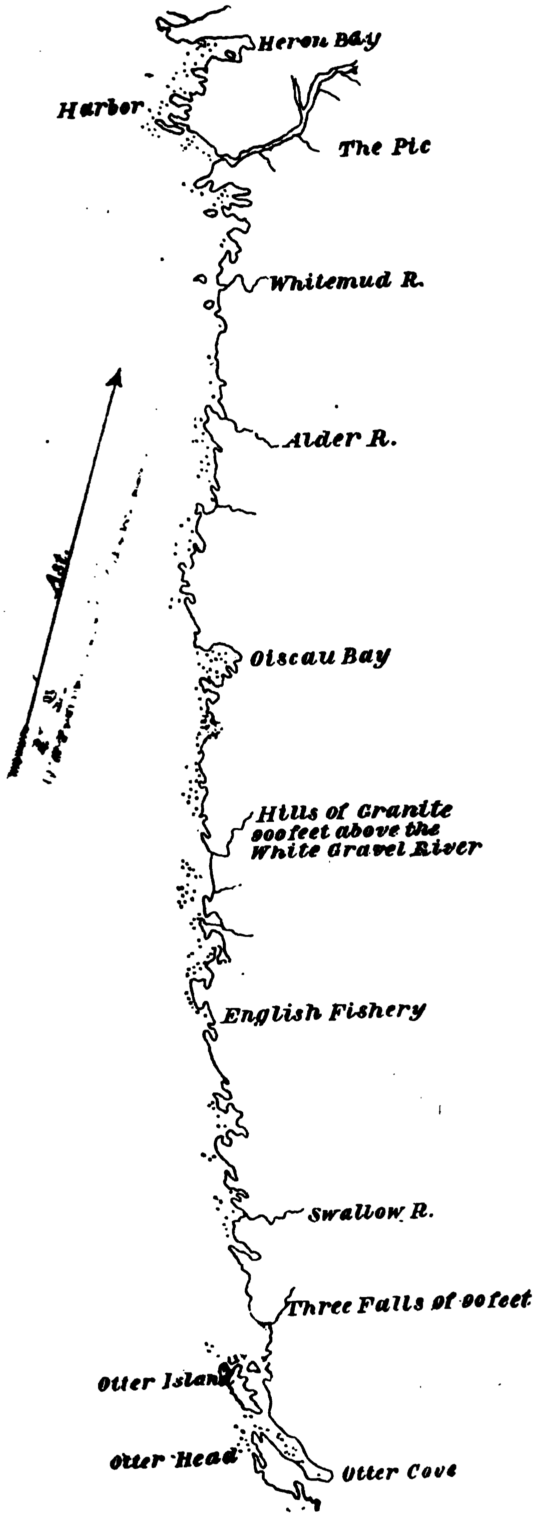


Fig. 3. The shore contour of the Archæan Province. Scale five and one-third miles to an inch.

of from two to five miles, and (2) a much more elaborate indentation of a minor kind, which is the most characteristic feature of the shore of the Archæan. It is in this minor indentation that the shore contour is most intricate. It gives the shore, when mapped on an adequate scale a distinct *suture*-like appearance, to understand which it is necessary to remember that the shore line is produced by the submergence of a hummocky or mammilated slope. The land and water seem to interlock much as two bones of a skull do. As regards the major indentations of the shore the controlling condition of their evolution, under processes of pre-lacustrine erosion, has doubtless been the variation in the petrographical character of the formations along the line of the present coast. The green stones of the Ontarian system of rocks seem to have been more resistant than the granite and gneiss of the Laurentian and have in some cases given rise to headlands. In other cases one portion of the Laurentian was probably less susceptible to secular decay than another and so stands out as a promontory. The law controlling the evolution of the form of the minor indentations is not apparent. It is the same as that governing the forms of the *roches moutonnees* and the hummocks. In neither the major nor the minor indentations is there any semblance of parallelism, the forms and directions of the bays and points being exceedingly diverse and irregular. In spite of the excessive intricacy of detail of the shore contour, the indentations of this line are very rarely sharply angular but are rather rounded, being practically the local partial contours of the hummocks and lumpy rock masses of the coastal slope. The present tendency of shore action is towards the simplification of the shore contour, but as pointed out in another place, it is only feebly effective on account of the smooth obdurate character of the rocky points and the consequent scarcity of shore drift to fill in the bays. A characteristic feature of the Archæan coast and one which is supplementary to the minor indentation of its shore line is the presence of the fringe of rocky islets lying close in to shore. These of course are but the summits of hummocks and *roches moutonnees* which have been so far submerged as to be completely encircled by water. See Fig. 3.

Shore contour of the Potsdam Province.—The extent of the Potsdam province, on the north side of lake Superior, is so limited and so broken up into isolated patches that any generalization as to the character of its shore contour would be of questionable value, were it not that the same province has an extensive distribution on the adjoining south side of the lake, under similar conditions. The shore contour of the province is that of a mature shore. In detail

it presents sweeping sinuous curves, and the few angularities are apparently due to the development of spits, or to the local accumulation of coarse glacial debris, in shallow water. The simplification of the shore line is far advanced, although there are some small bays without apparent bars across their entrance. Such bays are, however, very shallow. The general trend of the shore line is irregular, and has no dominant direction for the reason that the geological province is geographically, if not geologically made up of outliers of the more extensive formation of the same rocks on the south side of the lake.

THE HILL CONTOURS.

Inasmuch as the topography of the coast is, in its broad features, essentially pre-lacustrine, the shore contour is only a special case of the hill contours; and our consideration of this special case anticipates, in some degree, an account of the more general contours of the coastal slope. These contours, as they would appear on a topographic map, are, quite as much as the shore contour, characteristic for each province. In the Keweenian province the hill contours, inland from the brink of the shore cliffs, are prevailingly long sweeping lines, usually uniformly spaced for a constant vertical interval. On a map closed curves, indicating isolated hills, would not be numerous, and only in a very few cases, such as at Carlton Peak, would they approximate a circular form. These hill contours would not, however, have the same constancy of trend as that evinced by the shore contour of the present strand. This comparison of the shore contour with the hill contours brings into prominence the fact that at none of the higher stages of the lake has the shore of the Keweenian province been so simple a line as it presents for the existing strand. Many sinuousities, bays and headlands characterized the shores of the earlier stages of lake Superior along this portion of the coast.

In the Animikie province the hill contours would for the most part show a prevailing parallelism with the shore contour, but with a greater amount of indentation. The prevalence of mesa scarps and dykes would, as compared with the Keweenian coast, necessitate a great crowding together of contour lines; while on the tops of the mesas the same vertical intervals would be widely spaced. In their trend, also, these contours would show sudden bends and sharp angularity, features which contrast with the gentler curves of the Keweenian province. Closed curves would be even more exceptional than in the Keweenian, but would occur in the case of isolated mesas similar to Pie island.

In the Archæan province the hill contours are very distinct from those of either the Keweenian or Animikie provinces. Whatever general parallelism they may have with the present shore is obscured by their great irregularity. The hummocky character of the country would give rise to a great abundance of closed curves in contours of small interval, and these would constantly approximate circular and oval forms. The majority of the contour lines would be exceedingly serpentine in character, or suture-like as in the case of the present shore. For the same interval they would not be so uniformly spaced as in the Keweenian province, nor would they ever be so unequally spaced as in the mesas of the Animikie.

In the Potsdam province the contours, even of very small interval, would, on a map, be few in number, widely spaced, and sinuously straggling as is usual in nearly flat tracts.

COASTAL PROFILES.

Those elements of the coastal topography which are best expressed by profiles evince, as has been already remarked, a very striking dependence on geological conditions; and the profiles in each province are characteristic for it to a remarkable degree. The petrographical and structural features of the four provinces find very distinct expression in the form of the coastal slope.

The possibilities of variation in a topographic profile are seemingly great. As a matter of fact, however, there is but a limited number of *types* of profile actually met with in the inequalities of the earth's surface; and nothing would startle the geological eye more than to meet with certain profiles which are mathematically possible, and easily conceivable, but which are not developed by geological agencies.

It is not proposed here to enter upon a discussion of these types of profile in general, but a few may be enumerated as of dominant occurrence in lake Superior topography. For the sake of convenience the writer will take the liberty of specifying those different types of profile by definite names, some of which are in common use.

The Dip Profile—in which the slope is definitely conditioned by the dip of inclined strata. This profile is common as a portion of anticlinal, synclinal or monoclinal structures, and is of frequent occurrence where the full structure is not revealed. It also constitutes portions of the full profile of many tilted orographic blocks.

The Flat Profile—in which the vertical element is very insignificant; common in undisturbed horizontal strata, the upper beds of which are not much above the local base level of erosion. This would of course include base level plains of deposition. The same profile may also be found in base level plains of erosion.

The Mesa Profile—in which the vertical and horizontal elements are nearly equally effective and are manifest in the profile as actual vertical and horizontal lines respectively. Most common where table lands are wholly or partially circumscribed by cliffs of differential degradation.

The Strike Profile—the outline of a section of inclined strata taken parallel to the strike of the rocks. Theoretically the profile is characterized by a dominant horizontal line. In reality the horizontal line is usually interrupted and indented by features due to uneven erosion.

The River Trench Profile—the profile across a line of drainage, usually representing a distinct trench, the form of which varies according as the drainage is new or old—juvenile or senile—from the sharp V-shape of a mountain cañon to the broad flat-bottomed valleys of a base-leveled plain. On lake Superior the latter of these extremes is never found. With reference to their present base level all the streams are young and are actively cutting trenches. But they are mostly small and the cañons, with one or two exceptions, such as that of the Pigeon, below the falls, and the Kaministiquia, below the falls, are not imposing.

The Precipice Profile—in which the vertical element is greatly in excess of the horizontal, and which lacks the flat top of the mesa. The forms which give this profile may be developed in a variety of ways. It may be part of the fallen but not wholly revealed profile of many sea-cliffs. It is common in the forms resulting from stream erosion and along fault lines.

The Dyke Profile—usually the profile of a sharp ridge with a definite approximation to verticality on both sides, resembling two precipice profiles back to back. Frequently on lake Superior the vertical aspect of the profile is diminished by the adherence to the sides of the dyke of indurated portions of the country rock intersected by it.

The Hummock Profile—characteristic of the forms resulting from the gradual decay of massive crystalline rocks; very common in Archæan terranes where this character of surface now prevails, and also prevailed prior to the deposition of the earliest Palæozoic strata, although evidence of secular decay of the pre-Palæozoic

surface is exceedingly meagre. Rotundity is the chief characteristic of the hummocks so that *convex* curves mark their profile. The arrangement of the hummocks with reference to one another is very irregular so that no two neighboring profiles exactly agree, although the general characteristic is never lost.

The Talus Profile—the slope of repose of angular fragments of rock; common on certain parts of the coast of lake Superior but always subordinate to more important profiles, usually that of the mesa; never a dominant profile as in the case of cinder cones.

All of these profiles may be observed on the coast of the north side of lake Superior. Other types also exist, but it is believed that they are of minor importance for the purpose of this discussion, which does not pretend to be exhaustive. Some of these types may exist alone or in combination with others; while some exist only in combination. They may be regarded as *primary* profiles or of prime importance in giving character to the topography of the coast, being the results of sculpture, under various geological conditions, of the beveled edge of the rocky plateau which limits the lake basin.

These primary profiles are frequently, however, locally modified by the imposition upon them of secondary profiles due to former lacustrine action. These secondary or modifying profiles are those of the various shore embankments and terraces which have been developed at stages of the lake higher than the present. And it is these modifications of the coastal topography to which special attention is directed in the sequel. But first a brief comparison will be instituted between the primary profile of the different geological provinces.

Independently of their topographic character the profiles of a coast may be classified according to the direction in which they are taken with reference to the trend of the coast as, (1) the parallel profile and (2) the transverse profile. The topographic type which these two directions of profile exhibit in the different geological provinces will now be briefly stated.

THE PARALLEL PROFILE.

The Keweenian Province.—The parallel profile of the Keweenian province is characterized by the dominance of those special types of profile which have been designated the "strike profile," modified by the "river trench profile." Generally speaking, the strike of the rocks is parallel to the shore, and a general section through the coast close to the shore line and parallel to it would show a long approximately horizontal line notched by stream

trenches and the deeper coves of the shore. The vertical distance between the level of the lake and the line of the profile would be comparatively small, but would increase in proportion as the line of section was taken more and more remote from the shore.

The Animikie Province.—In this province a section of the coast parallel to the mean trend of the shore, or roughly coincident with it, would show in the western part a prevailing series of "dyke profiles," and in the more eastern part very pronounced "mesa profiles." The dykes are on a grand scale, and as they form the axes of several of the long points which condition the bays, they appear to advantage in a section across these bays, though cutting them obliquely. Many of these great dykes, though rising in precipitous ridges, some nearly a thousand feet in elevation, have considerable masses of the adjacent country rock adhering to their sides, while others have lost this and rise shear from the water. This prominent dyke topography is practically absent in the Keweenian, except at a few localities, of which the vicinity of the Saw-teeth is the most notable. The horizontal line of the mesa profiles differs from the same line in the strike profiles of the Keweenian in the greater vertical interval between it and the lake level, and also in the fact that this interval is practically constant, however remote inland the section may be taken. A marked characteristic of the coast of the Animikie province, also which appears in this profile, is the talus profile, subsidiary to that of the mesas. In none of the other provinces do these talus slopes appear.

The Archæan Province.—The characteristic parallel profile of the coast of the Archæan province is that of the hummock, and does not differ essentially from the transverse profile given in generalized form in Fig. 6, except, that in a section coinciding with the mean trend of the shore, it would be broken by intervening stretches of water.

The Potsdam Province.—In this province the parallel profile is that designated as the "flat profile," and is somewhat similar to the strike profile of the Keweenian. It would differ from the latter in being closer to the line representing the lake level and in being more nearly horizontal, or so lowly arched as to be sensibly horizontal, and would be free usually from the interruptions due to the stream trenches and sharp coves of the Minnesota coast.

THE TRANSVERSE PROFILE.

The Keweenian Province.—If one leaves out of consideration the hummocky gabbro hills of Duluth, which are of limited extent, the transverse profile of the Minnesota coast is characteris-

tically the "dip profile" in combination with which at the water's edge is a "precipice profile," where the slope of the coast breaks away shear. There is a uniform and constant lakeward dip of the bedded volcanic flows and injected sheets of which the series is composed, and the slope of the coast is clearly conditioned by this dip. At a few places along the coast the underlying basement upon which the Keweenian rests emerges in the beautifully rounded hummocks so characteristic of the Archæan terraces, but these are so limited in extent that they do not affect the character of the profile except in one case. This is at Carlton peak, where, at a distance of something less than two miles from shore, a huge dome of the underlying basement rock projects through Keweenian strata and gives its character to a portion of the profile. To the southwest of Carlton peak, also, a heavy sheet of coarse gabbro, several hundred feet in thickness, probably the remnant of a great intruded sill, rests upon the Keweenian flows and has a dip conformable with them, giving the appearance of a tilted mesa with a great scarp facing the northwest, and a less pronounced mesa edge facing the lake. Other localities where the characteristic "dip profile" is notably deviated from are, in the vicinity of the Saw-teeth, where there are important irruptive masses, intersecting the Keweenian; at Farquhar's knob, a ridge whose structure has not been investigated; at Beaver bay, where there is some topography of the mesa type; and at Grand Marais where, to the west of the harbor there is also a mesa ridge and to the northeast a moranic accumulation. The precipitous termination of the coastal slope, near the shore varies somewhat in character. Where the rock is a single mass from the water's edge to the top of thecliff, it is usually almost or quite vertical, as at the Palisades where the cliffs have their maxium elevation of 210 feet. Where the cliff is composed of different strata it is frequently step-like in character.

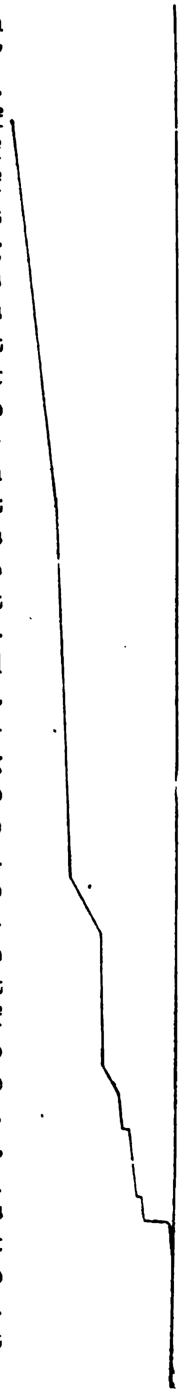


Fig. 4. Transverse profile of the Keweenian Province modified by the presence of two terraces.

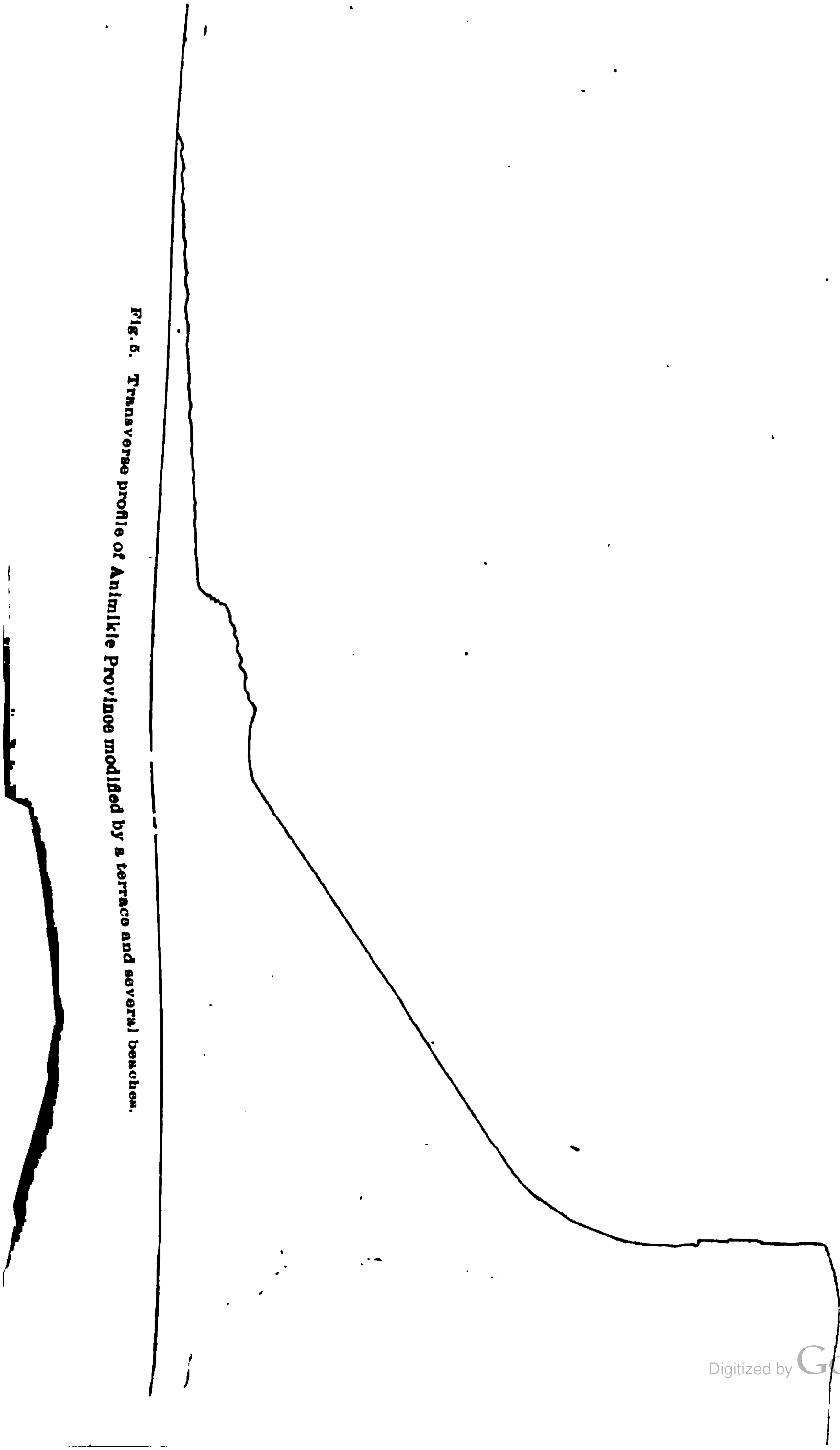


Fig. 5. Transverse profile of Animikie Province modified by a terrace and several beaches.

The transverse profile of the Minnesota coast is frequently modified by the presence of embankments and terraces of the ancient strands of the lake and it is probable that were the timber removed this modification would prove to be much more extensive and important than can at present be recognized.

The Animikie Province.—The transverse profile of the coast of the Animikie province is characteristically that of the mesa, usually with the subsidiary talus profile, but sometimes without it. The dyke profile is, however, not uncommon in the same part of the coast where it appears in the parallel profile. In the valley of the Kaministiquia the transverse profile is exceptional, as will be understood from what has been said of the development of the delta of that stream in a former part of this paper. At Port Arthur a trap sheet, such as usually forms the cap of the mesas, dips towards the lake and passes beneath it, and there is other evidence of local disturbance so that the profile here is abnormal. It is, however, more effectively modified here by the embankments of the former strands of the lake than is usually the case. Towards the head of Thunder bay the transverse profile crosses both the Animikie formations and the underlying Archæan, which emerges from beneath it, and the profile is correspondingly complex.

The Archæan Province.—Throughout the coast of the Archæan province the hummock profile prevails in sections transverse to the coast as in those parallel to it. The exceptions are few and are quite local. Where the coast is coincident with the strike of the schistose rocks, however, the hummock profile is combined sometimes with the precipice profile, and also at some few localities where sea-cliffs have been developed in massive rocks. Two of the exceptions to the general hummock profile are of special interest. In the profile of the coast to the east of Rossport there are places where a very distinct precipice appears with a shelf at its base, not immediately at the shore, but at some little distance from it. Resting at the base of the cliff are small outliers of the Keweenian lava flows, in place, showing clearly that the cliff is pre-Keweenian in date. Other portions of the hummocky slope of the north coast of the lake have small outliers of such volcanic rocks and also of Keweenian sedimentary rocks which locally modify the profile to a minor extent.

The second exception is also of exceptional occurrence. It occurs where the line of profile crosses some of the numerous trap dykes which intersect the Archæan of this coast. Very frequently these dykes have disintegrated much more rapidly than the adjoining country rock so that the spaces formerly occupied by them are now

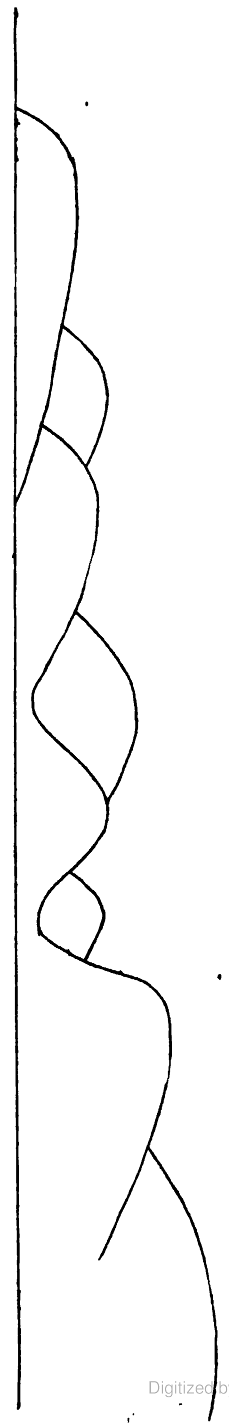


Fig. 6. Generalized transverse profile of Archæan Province.

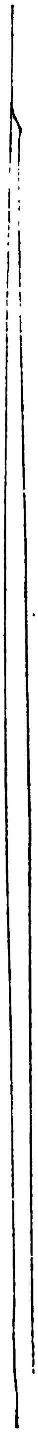


Fig. 7. Transverse profile of Potsdam Province.

sharp trenches of rectangular section. In short the hummock profile is modified by the presence of what may fairly be termed a *negative dyke profile.*

The Potsdam Province.—The transverse profile is here again the flat profile of low-lying undisturbed strata. Within the limits of what may fairly be termed the coast, however, we pass from the Potsdam to the Archæan and the two types of profile would commonly appear in combination.

THE ABANDONED STRANDS.

Considered as purely topographic features the abandoned strands of the north side of lake Superior appear most prominently in the transverse profile, as modifications of the primary coastal slope. This modification of the profile is only of local occurrence and therefore topographically not of great importance. Many extensive portions of the coast might be passed in review without a suspicion being raised in the mind of the observer of their having served as a succession of shore lines. The strictly topographic interest is therefore quite subordinate; and it is only when we begin to take cognizance of the various and wonderful physiographic changes which have conditioned the different stages of the lake that the real interest begins. The shore topography on the hill sides, even if it were far more continuous than it is, is but the registration of the former existence of conditions and activities other than those of the present, and it is the possibility of acquiring clear conceptions of these vanished conditions that gives zest to the inquiry. The nearness of this wonderfully different state of affairs to the present and its evident gradation into normal familiarities of our own day give the chase for the facts even a dash of excitement; so realistic is the picture of the geologic yesterday, conjured up by the contemplation of beautifully, perfect shingle beaches and terraces, one, two, three, four, five, and six hundred feet in the air.

But even this interest, strong as it is, has been made subordinate by the writer to another. The chief object in the inquiry has been to endeavor to ascertain by a careful series of measurements whether the old strand lines of the lake have maintained their original horizontality or have become warped and tilted as in the case of the shore lines of lake Agassiz and lake Iroquois. With this object in mind it was clearly recognized at the outset that it would be hopeless, owing to the merely local development of shore features, to settle the question by attempting to trace out continuously any single strand line or any set of such lines. It was, however, believed that the strands of different vertical series could be

correlated, unless there had been rather complex movements, by carefully comparing the intervals between them. Whether the shore lines had been tilted or not, the interval between them would be constant, provided always that any tilting that might have occurred was subsequent to the abandonment of the lower of the set of strands considered.

In order to effect such a correlation the most accurate possible data were necessary, and steps were accordingly taken to ascertain the elevations of the various features indicative of shore lines by precise engineering methods. I was accompanied throughout the exploration by Mr. Louis A. Ogaard, who, assisted by Mr. Fred Kiehle as rodman, carried lines of levels from the shore to the various points designated by me in any series of beaches and terraces, using a Y level carefully adjusted from time to time. The figures given in descriptive notes which follow and in the table are the figures from his level book, and the writer vouches for the painstaking care with which this instrumental work was done. In these figures the decimals are not dropped for two reasons. (1) The figures do not represent always the actual level of the water. The crest of a beach is always above the level of the water line at which it is formed; the rear of a terrace may be sometimes above the actual water line and occasionally it may be below it, so that in nearly all cases a correction has to be made for the actual water level. The amount of this correction is never definitely known so it has been thought best not to apply it, but to give the figures for the actual observation. In this connection it is well to note that many of the apparent discrepancies in strand lines which are correlated in the table are doubtless due to the varying value of this correction. On the present shore the crests of living beaches facing the open lake were frequently measured at all elevations betwen 9 and 14 feet above calm water. In less exposed parts of the shore they usually did not exceed 6 feet in hight. Again, the base of a sea-cliff is commonly one or two feet above the calm water, though occasionally it coincides with the lake-level closely, and the rear of terraces forming at the mouths of streams is usually below the lake-level. (2) The second reason for giving the actual figures of the level book is that in a great many cases, particularly with reference to beaches, it was found to be entirely possible to determine the elevations accurately within a fraction of a foot, so sharply horizontal are these features, and there seems to be no good reason for giving figures less accurate than were obtainable. It will be understood then that the figures given do not represent precisely the actual water levels, but simply the eleva-

tion of shore features developed at the various stages from which the actual water levels may be inferred, within certain considerable limits of error.

Before discussing the data obtained by the inquiry or formulating any generalizations it will be well to first become familiar with our facts, and to this end a brief descriptive account is given of the various series of strand lines observed on the coast. The results of the levelling also are summarized in the table at the close of the descriptive notes. In these notes the word series and the number attached to it has the same significance as in the table. The Roman numerals also refer to the table. The table is expressive of a correlation which is discussed in the pages which follow it.

DESCRIPTIVE NOTES.

Series 1.—Duluth West.—On the hills of the city of Duluth a very clear and excellent registration of some of the higher stages of the lake may be observed. The city, as is well known, is being built upon the steep lakeward slope of a massive, rounded range of coarsely crystalline gabbro, which within the city limits rises to an elevation of probably 800 feet above the present level of the lake. On the upper portion of this slope the topography is such that it has been found a convenient and easy matter to construct, as part of the general embellishment of the city, a magnificent carriage drive around the brow of the hill. This carriage drive follows a contour line at an average elevation of perhaps 470 feet, and is known as the Lake View terrace.

It requires but a cursory inspection to see that the particular phase of the topography which has suggested and made easy the construction of this Lake View terrace is due to the imposing upon the steep and rocky hill-side of a feature which has been developed along a former shore line of the lake. This feature consists of a pronounced natural terrace or shelf facing the open lake. It varies considerably in width, being narrow where it rounds the shoulders of the hills and widening out very much in the bays and recesses. It has a gentle but constant slope lakeward, and ends rather abruptly on its outer edge, dropping away into the general steep slope of the hill. The back of the terrace is limited usually by the rounded glaciated forms which characterize the upper portion of the gabbro mass. These rounded forms at the back of the terrace are in places replaced, however, by vertical cliffs of gabbro with large blocks which have fallen from its face scattered about the rear of the terrace and partly imbedded in it. This vertical face of rock

FIG. 1. LAKE TERRACE WITH SEA-CLIFFS IN BACK GROUND, END OF NINTH AVE. W., DULUTH. PARTIALLY MASKED BY SUBSEQUENT WASH AT THE RIGHT. (P. 233.)

FIG. 2. BOULDER BEACHES, HORSESHOE BAY. (P. 247.)

with its talus of angular blocks represents undoubtedly a "sea-cliff" and is like the terrace a product of shore action. An example of such a sea-cliff may be seen near the upper end of Ninth Ave. West. [See Pl. VIII, Fig. 1.]

The material of which the terrace is built consists of surf-rolled boulders, pebbles, gravel and sand. The arrangement of this material is well seen in the cuts which have been made at a few points in the construction of the drive. In the cut at the upper end of Ninth Ave. W. about 150 feet in front of the sea-cliff just mentioned, the terrace has been sunk into so as to afford a vertical section of 9 feet. The lower 6 feet of this section show sharply bedded gravel and sand with occassional boulders up to one foot in diameter. [See Pl. X, Fig. 2.] The upper 3 feet of the section although composed of the same materials is not distinctly bedded, but this obscuration of the stratification may be due to the action of vegetation. The strata intersect the vertical plane of the section usually in quite horizontal lines. At the south end of the cut, however, oblique bedding of alternating wedges of gravel and sand is well seen, the dip of these beds being 25 degrees and less.

The relations of the various factors of the topography at the head of Ninth Ave. W. is illustrated in the diagrammatic section.

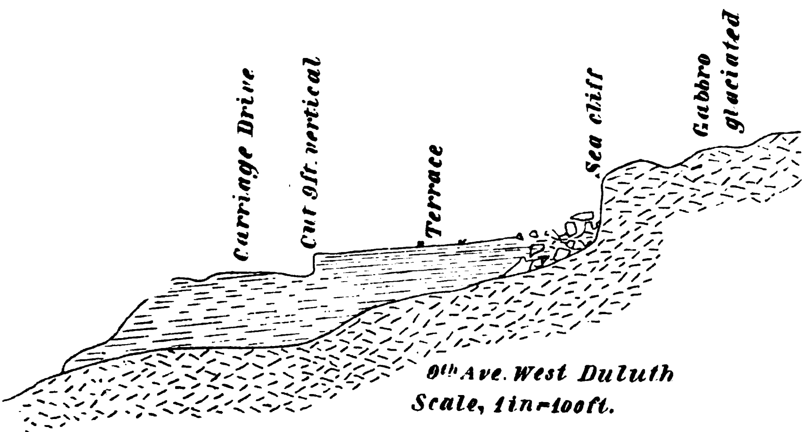


Fig. 8. Section at the head of Ninth Ave. W., Duluth. Elevation of terrace, 476 feet.

The rear of the terrace in front of the sea cliff was found to be 475.9 feet above the lake (XXIX). The structure of the terrace shows that while primarily it is a wave-cut feature, the cut shelf of rock and the slope below it is covered with current-sorted material which was probably brought down by minor drainage.

Evidence of shore lines at lower levels in the western part of Duluth were not satisfactorily observed, although they will probably be found if looked for on the slopes between Duluth and Fond du Lac.

At a higher level, however, there is a great beach which spans an embayment in the hill front and stretches continuously between the two shoulders of rock which are at the head of Sixth and Eighth Aves. W. respectively. The Seventh avenue inclined railway, which was under construction at the time the examination was made, terminates on this beach, the crest of which was found to have an elevation of 534 feet (XXXI). The presence of the beach is clearly revealed by the topography which it imposes upon the hillside. The contrast with the unaffected portions of the hill is striking. The horizontality of the beach crest is the feature which first attracts attention, the longitudinal profile of the beach with the rock on either side being not unlike that of the upper half of a dumb-bell, thus ⌒——⌒. The transverse profile shows the characteristic undulatory front slope of shingle beaches, the descent being by a succession of rounded steps. The same profile shows also a well marked lagoon hollow behind the beach. The ground plane shows that this lagoon hollow is entirely inclosed by the straight beach in front and by the rocky slopes of the hill on the sides and in the rear, so that the contour of its rim is roughly of the form of the letter D.

At the south end the beach has been quarried for road ballast and there the material which enters into its composition and the arrangement of the same is readily observable. The material consists chiefly of pebbles and boulders which range in size from two to six inches and have a prevailingly rounded form. There are a few large boulders up to two feet in diameter and a good deal of finer gravel. Stratification is not discernible in the mass of the beach and the pebbles and boulders are piled up in the irregular fashion so well exhibited by the living beaches of the lake. There was no longitudinal section which would permit of an observation as to the sorting of the material according to its relative coarseness. In the upper part of the beach there is some fine gravel and sand which shows a stratiform arrangement, but this is probably due to wash from the lagoon, since such drainage would doubtless have kept a way open for itself through the beach.

The undulatory front slope of the beach extends from its crest at an elevation of 534 feet down to the rear of the terrace already described at an elevation of 475.9 feet, and the relations seem to warrant the inference that the higher strand line is the older and

that the water subsided by stages till it arrived at the one marked by the Lake View terrace, where it remained constant for a sufficient length of time to evolve the striking feature of the togography, the terrace being in fact cut into the slope of the older and higher beach.

Series 2.—Duluth, Tenth Ave. East.—Near the head of Tenth Ave. East, three distinctly marked strand lines are recognizable. The highest of these is a wave-built terrace of pebbles and boulders resting on a rocky slope and facing the open lake. Careful levelling established its elevation at 534.8 feet (XXXI) which agrees within a foot with the altitude established by an entirely independent line of levels for the beach at the head of Seventh Ave. West. From this elevation down to an altitude of 436.2 feet, or in round numbers a vertical distance of 100 feet, there is a continuous bank of beach material comprising boulders, gravel and coarse sand, lying upon the slope of the hill. On the front of this great embankment there is a level terrace, which, while not very broad, is persistent and on being traced southward is found to abut directly against the rocky slope at a place where the upper terrace is wanting. This second terrace was found to have at the rear an elevation of 473 feet (XXIX) which again agrees very closely with the figures obtained for the rear of the Lake View terrace in West Duluth. The structure of the upper terrace is not revealed by any section; but below the 473 foot terrace there have been a number of excavations for road ballast and in these it is seen that this lower part of the gravel bank is distinctly stratified with a dip in the direction of the slope of the hill, but at a much less angle. There is a small ravine to the left of the higher terrace and there is little doubt that the stream which flowed down this ravine supplied the material of which the whole of the 100 foot bank is constructed; and the development of the two terraces and the stratiform structure seen below the second one is probably explained by the following considerations:—

The bedrock of the ravine is much lower than the upper terrace (XXXI), and was so when the lake stood at the level at which the terrace was built. The ravine after becoming itself filled with detritus to the level of the lake would supply the material for the terrace, and besides this there would be much which would be carried down to the subaqueous slope and arranged by the varying currents into strata. As the level of the lake subsided the ravine would be cleaned out and its accumulations spread out on still lower slopes also in bedded fashion. In this way the 100 foot bank of gravel, etc., stratified in its lower part, would have been

accumulated. The strand line XXIX represents a stage in the recession of the water, at which, as in West Duluth, a second terrace was imposed upon the slope of the growing bank, partially cutting into the flanks of the upper terrace.

At the foot of the rather steeply inclined 100 foot bank of beach material, the slope suddenly changes and flattens out into a broad, gently inclined terrace in which no rock in place is seen. The rear of the terrace was found to have an altitude of 436.2 feet (XXVII). Its surface is composed of a dark earth in which are embedded scattered boulders, and it is covered with grass or timber so that its substructure is not apparent. On following the rear of this terrace northward beyond the gravel pits, it is found to abut against the *roches moutonnees* of the hill-side without the intervention of the gravel. The age of this terrace relatively to the gravel terraces above it is doubtful. It is uncertain whether the gravel bank rests upon the rear of this terrace or whether the terrace is imposed upon the lower flanks of the gravel bank. Owing to the absence of natural sections no ready answer presented itself to this question, and time was not taken to investigate it. It is possibly an older terrace, but evidence of this supposition is lacking.

Series 3.—Hardy's Schoolhouse.—Near the eastern limits of Duluth, in the vicinity of Hardy's schoolhouse, there is a magnificent illustration of that phase of topography which is due to the development of a bar beach and delta deposit at the mouth of a valley, which has been the channel of a stream flowing into a lake at a level now abandoned. The altitude of the crest of the barrier beach was found to be 509.5 feet (XXX) above the lake. Northward from it there extends a forest-clad, rock-walled valley about a mile wide at the mouth where spanned by the barrier beach. About the mouth of the valley are several isolated rocky hills which evidently formed islands in the lake when it stood at this high level. They rise from out of the beach formation or from the flat-lying delta deposits farther out which represents the shoals of the old lake bottom. The crest of the beach has a curvilinear form and extends in a southwesterly direction from the rocky knob at the schoolhouse, which stands at its northeast extremity, to the rocky hills which rise at the back of the city. In a general way it seems concave towards the valley, but it is by no means a simple ridge. It has a very extensive aerial distribution, and while on the side it presents sections, as along the line of the electric tramway, which are simple lowly-arched ridges of beach material, towards the middle

FIG. 1. GRAVEL CUT. SECTION ACROSS HARDY'S SCHOOL HOUSE BEACH, EAST DULUTH. (P. 237.)

of the valley it spreads out and grades into a broad delta. The crest of the beach is higher than the valley bottom to the north of it and also higher than the flat tract to the south. The section referred to on the line of the tramway near the schoolhouse is a cutting made in the construction of the road and displays a vertical section of about 6 feet of evenly bedded and obliquely bedded gravels with some sands. [See Pl. X, Fig. 1.]

On the lower slopes of the eastern part of the city of Duluth and for many miles northeastward along the coast, there are definite indications and suggestions of terraces when the land is viewed from a distance. There are two circumstances, however, which interfere with the recognition and location of these terraces at close quarters. The first of these is that the geological structure of this part of the coast is such that the strata dip lakeward at about the same angle as the slope of the terraces, so that the changes of inclination in the transverse profile are not sufficiently accentuated to permit of reliable determination of the line of the abutment of the terraces upon the hill-side. The second unfavorable circumstance is the prevalence of timber which obscures the surface but allows the general effect of a terrace to be sometimes dimly apparent at a distance. On account of these conditions, no time was spent in trying to locate shore lines between Duluth and Two Harbors.

Series 4.—Two Harbors (D. & I. R. Ry.).—On the line of the Duluth and Iron Range railway, northward from Two Harbors, one very strong suggestion of a strand line may be observed in the vicinity of mile post 32, in the abutment of a sloping plain against a series of morainic hills. This change of the character of the surface comes out most distinctly when viewed from a distance. From a hill top on the shore of the lake near Two Harbors, even although the country is wooded or only partially burnt, the effect of a plain abutting upon the hills is quite distinct. The corresponding change in the slope of the surface is recorded in the railway profile as published in Winchell's Iron Ores of Minnesota, plate No. XXXVII, where the rear of the terrace at the 32nd mile post is given at 475 feet (XXIX).

The railway yards and station, at the town of Two Harbors, are also on a terrace whose limitations to the northwestward could not be definitely recognized. The elevation of this plain at the railway junction is, according to the same authority, 35 feet above the lake.

Series 5.—Beaver Bay.—The mouth of Beaver river is well protected from south and southeast winds by a bold head, which, at its extremity, presents to the lake vertical cliffs over 100 feet

high, but which is connected to the main land by a rocky ridge about 50 feet on an average above the lake. This ridge is partially mantled by old beach material and sand. The stream, after emerging from the gorge through which it discharges into the lake, hugs the northeast side of this protecting ridge for a couple of hundred yards, and on the other side of the stream there has been built up, by the joint action of the stream and easterly or northeasterly storms, a well defined spit. [See Pl. XII, Fig. 2.] This spit seems to be crowding the stream against the ridge, and in consequence it is cutting a terrace in the soft material which flanks it. This same condition of things seems to have obtained when the lake was 20 feet higher than at present; for, on the northeast side of the ridge, parallel to the present stream, and 20.1 feet (III) above it is a distinct terrace, which, while doubtless due to stream action, yet is in such a position that it must have, at the time of its formation, corresponded at its rear to the then level of the lake.

The next old strand line observed at Beaver bay is on the slopes above the base of the spit referred to, where a small but distinct terrace is found at an elevation of 79.9 feet (VII). The terrace looks out over the lake and lies to the northeast of the mouth of the gorge from which the stream emerges. The hill in which the terrace is cut is apparently moranic material resting in a rocky slope. There is doubtless also an admixture of stream detritus but the heavy sward prevents satisfactory determination of the structure of the hills.

Farther up on the slopes of this hill a broad terrace has been built up evidently in the form of an embankment of the stream detritus dumped into the lake at its higher stages. This terrace is best seen in the cultivated fields on the west side of the Beaver river. It abuts against the steeper hills as an old shore-line near the grave-yard at an elevation of 126 feet (XI). A few hundred feet down the slope of this broad and gently-sloping terrace is a low beach-like ridge of fine gravel which is probably of the character of barrier beach at 114.8 feet (X). On the east side of the river the hill rises somewhat uniformly in the form of a broad sloping well timbered terrace. A wagon road through the timber shows that while the slope is uniform in general it is uneven in detail, is strewn with boulders, and characterized by abundance of red mud. This broad terrace at about a mile back from Beaver bay encircles a rocky hill which rises from the rear of the gentle, nearly flat slope with steep sides which in places are absolutely vertical for over one hundred feet. The sides of the hill at these places present the character of a sea cliff and the abutment of the

gentle boulder-strewn terrace against this rocky hill is taken to be the mark of an old strand line, at a time when the hill was an island of the lake. This abutment was found by our measurement to be at 313.9 feet above the lake (XXII). The hill thus encircled has a diameter of perhaps one-half mile and rises to about 700 feet above the lake. It was ascended to the summit, but no red mud and very few boulders were seen above the terrace plane. Nor were any indications of higher strand line observable either on this hill or on the surrounding hills as seen from its summit. The summit affords a good view of the surrounding country and the terrace in question appears to run in between the hills as a valley bottom which as far as could be judged in the timbered state of the country, rose on the flanks of the hills to a constant level. Between this hill and the lake on the general slope of the main terrace there is a subordinate terrace at an elevation of 173 feet (XV).

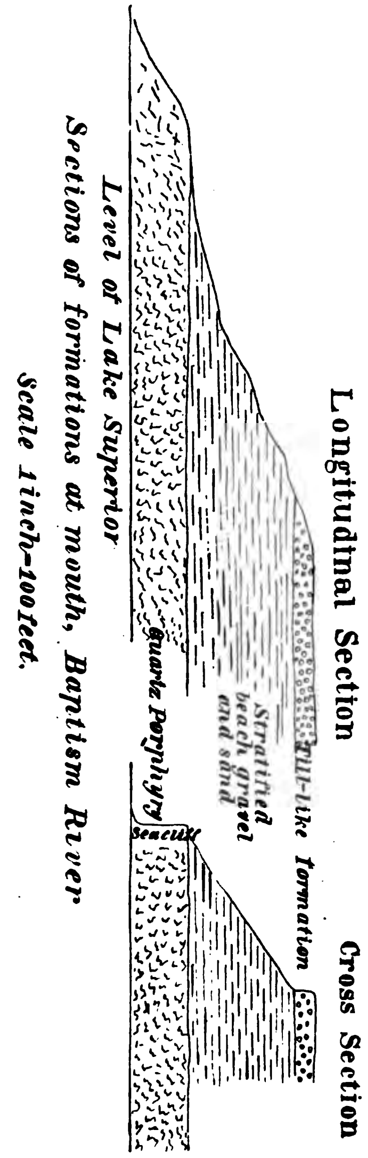


Fig. 9. Sections at mouth of Baptism river.

Series 6.—Baptism River—Just east of the mouth of the Baptism river below the Palisades, a clear-cut sea-cliff facing the open lake reveals a unique and interesting section. The cliff rises practically from the present level of the lake, but there is a low beach a few yards wide between its base and the edge of still water. The lower 30 feet of this sea-cliff is vertical and consists of one of the acid formations of the Keweenian volcanic series which are usually so intimately jointed and so susceptible of mechanical

disintegration. Upon this rock rests a thickness of over 50 feet of stratified material which presents all the characters of a shore embankment.

It is made up chiefly of coarse sand, gravel and boulders entirely uncemented. Upon this stratified beach-like material rests about 11 feet of heterogèneous material which has all the characters of boulder till. The part of the sea-cliff above the lower vertical wall of rock, although made up of these incoherent materials, presents at numerous places a vertical escarpment in its upper part with a talus mantling its lower part down to the brink of the rocky cliff. The section parallel to the shore, as seen when approaching the shore from the lake, is shown in Fig. 9, as is also the cross section.

The upper incoherent portion of the sea-cliff although presenting a front which stands somewhat further back from shore than the lower rocky portion is not apparently receding at a faster rate, but is receding *pari passu* with the undermining of the rocky foundation on which it rests. The line of demarkation between the rocky lower portion of the sea-cliff and the stratified material which rests upon it is a roughly horizontal one and seems to be the trace of an old plain which is of the nature of a terrace. The dividing line between the stratified beach material and the third or till-like member of the section, is also a horizontal line and is sharply marked. There seems to be no good ground to doubt the beach character of the middle member of the section for the following reasons: (1). The character of the material is that which usually constitutes shore drift. (2). Its stratification is similar to that of embankments composed of material not too coarse. It is both horizontally and obliquely bedded, the planes of the false bedding being frequently discordant. (3). The apparent embankment extends out from the west side of a bold promontory which lies to the east of the Baptism river and the material is coarser near this rocky ridge than further from it. (4). It faces the open lake and extends across the front of a valley. In view of these facts the formation is interpreted to be an embankment of the character of a beach bar that once crossed or partially crossed the mouth of a bay into which the old river discharged. The material of which the embankment is built is partly foreign, doubtless brought by the stream from morainic accumulations inland, and partly local from the mechanical disintegration of the cliffs. The upper member of this section, as has been stated, presents the heterogeneous character of boulder till. In places it is a pure red plastic clay with only occasional pebbles in it, but quite devoid of structure; a

few yards away this will merge into a clay mixed with sand and pebbles in the most irregular fashion, together with numerous boulders both rounded and angular up to two feet in diameter. Could the formation be shown to be boulder till of glacial origin, the section would be of great interest in connecting the old high leads of the lake with the presence of glacier ice at a time *posterior to* the primary glaciation of the region. The suggestion that this till-like formation is of glacial origin is sustained in a measure by the fact that it is found at the mouth of a short valley at the upper end of which are ranges of hills much higher than are usually seen on this coast, and which might have served as a gathering ground for local glaciers. In spite, however, of these suggestions of glacial causes, the origin of the formation must be for the present regarded as problematical, and the evidence inconclusive. In some of the western placer mining districts the heavy beds of stream detritus, consisting of boulders and pebbles of greatly varying sizes imbedded in clayey matrix, and devoid of definite arrangement within a given bed of great thickness, resemble closely much of the material which sometimes is called boulder till and referred to glacial origin.* In view of the insufficient examination of the surrounding conditions nothing beyond suggestion is offered as to the origin of the till-like stratum. It is assumed that the summit of the stratified gravel is the approximate crest of a barrier beach which by some means has been covered by the till. The summit is 83.8 feet above the level of the lake and it thus falls into place with strand line VII. On the upper or westerly side of the mouth of Baptism river, behind the club house, there is a distinct wave-cut terrace which has been carved out of a morainic accumulation, the rear of the terrace being 49.0 feet above the lake (V). The terrace has a very low angle of slope and is strewn with boulders which project above the surface, giving it the character of a boulder pavement, in the sense in which Prof. J. W. Spencer uses that term. The sea-cliff behind the terrace is low and has been rounded by atmospheric waste. The morainic material rests upon the same terrace-like platform rock as that observed on the east side of the river. The terrace and sea-cliff face the open lake.

*Formations of the character commonly designated as boulder clay may, it seems to the writer, in some cases have an origin greatly different from that at present ascribed to them and proper criteria of a purely petrographical character, so to speak, for discriminating between the true glacial formations and those due to other agencies are not yet formulated. Other criteria are of course available, such as the form of the mass, its relation to adjacent formations and other conditions of occurrence. But there seems great room for error if we rely on the character of the formation petrographically considered as a means of recognizing its mode of development.

Series 7.—Saw-teeth.—About three miles east of the mouth of Baptism river in the vicinity of the Saw-teeth, a search was made for terraces at a place where the country had been burnt and the jungle appeared to be passable. None were seen from the shore, and the fact that the search proved successful warrants the belief that at many places along the Minnesota coast ancient terraces and beach lines will be revealed as the timber is cleared. At the locality in question, a great embankment of shore drift mantles the underlying rocks up to a level of 130 feet above the lake. The upper limit of this embankment forms a horizontal contour around the hill and marks the rear of the highest terrace. Above it the hill rises with an acclivity of about 25 degrees to a hight of about 300 feet above the lake. The terrace has a slope of perhaps 5 degrees and at the place examined is about 150 feet wide. There is no trace of water-worn material on the rocky slope above the rear of the embankment, only scattered angular blocks of local origin; and from the summit of the hill no suggestion of higher terraces was obtained from an inspection of the surrounding, thickly-wooded hills. The terrace (XXI) probably belongs to the "cut and built" type of Gilbert, but no well-defined cliff has been developed and the accumulation of shore drift has been proportionately more rapid than the cutting action, a fact due doubtless to the proximity of streams. About 150 feet from the rear of the embankment, the upper terrace is limited by the sea-cliff of the next lower terrace. The sea-cliff, having been cut in the incoherent material of the embankment, is well defined, although its slope is something less than the angle of repose. The terrace at the base of this sea-cliff is only 50 feet wide and has an altitude of 99.5 feet (IX). Below this is another low sea cliff, the base of which is 84.5 feet high (VII), at the rear of a broad, gently-sloping terrace which extends for nearly one-fourth of a mile to the brink of the cliffs above the present shore.

Series 8.—Carlton Peak—From the vicinity of the Saw-teeth to Carlton peak fairly definite suggestions of two, and in some cases more than two terraces are obtained by an inspection of the coast from the lake. The country is, however, heavily timbered, and experience proves it to be impracticable to locate them within a reasonable time by crawling through the jungle. On the slope from Carlton peak to the shore the timber has been burnt, and by hard scrambling through the windfall it was possible to reach the terraces and ascertain their elevations approximately by aneroid observations. The figures obtained by this means were 80 feet, (VII) and 125 feet (XI) respectively, above the lake for the rear

parts of two very gently sloping terraces that have been cut in a broad embankment of soft material which must have accumulated at still higher stages of the lake. The precise registration of these higher stages was not observed, but the conditions of examination were unfavorable, and it is probable that higher terraces on the flanks of Carlton peak will be found.

Series 9 and 10.—Poplar River—The Poplar river cuts through a broad embankment of sand, gravel, etc., which mantles the rocky slope of this part of the coast for many miles. The front of the embankment overlooking the lake descends rapidly to the present shore by a succession of cliffs and cut-terraces which have been carved out of the main embankment at various successively lower stages of the water subsequent to that at which it was accumulated. The brink of the main embankment is about 116 feet above the lake, and from this point its upper slope rises very gently landward for nearly two miles to an elevation of about 300 feet where it abuts sharply against a steep range of a gabbro. The general character of the topography and the underlying structure is analogous to that described at Beaver bay, where a broad gently-sloping terrace of incoherent material abuts on precipitous rocky hills at an elevation of about 314 feet. The rear of this broad terrace at Poplar river was only ascertained very approximately by an aneroid observation, so that the figures are not incorporated with the more precise data of the table. The wooded character of the country practically prevented precise observations at points distant from the shore without an expenditure of time, labor and money, which would have been inconsistent with the modest plan of our operations. Although the newer terraces carved in the front of this main embankment face the open lake, they are in the immediate vicinity of the mouth of the stream, and the stream currents have doubtless played an important part in the development of the terraces, supplying and removing detritus contemporaneously with the cutting action of the waves The terraces and cliffs are all remarkably sharp in cross profile. The terraces are narrow and vary but little from horizontal. The angle of slope of cliffs was carefully measured and three were found to have a declivity of 28°, two of 27°, and one (the lowest) of 32°.

The lowest terrace of the series is a wave-built terrace, and is only 6.9 feet (I) above the level of the lake at its rear, where the fishermen's boat-houses stand. Towards the lake it grades into the present shore. The higher terraces have none of the characters of wave-built structures so far as can be discerned. At

the summit of this series of terraces and cliffs, just at the limit of the main embankment, is a beach-like ridge with somewhat lower ground behind it and a series of minor, succesively lower, parallel ridges on its gentle lakeward slope. This ridge is interpreted to be a barrier beach developed at a favorable stage of the emergence of the coast. The accompanying cross profile was plotted to scale in the field from precise measurements.

On the east side of the mouth of Poplar river only three distinct strand lines have been registered on the front of the main embankment. These are, a well-formed wave-cut terrace facing the lake at an elevation of 78.4 feet (VII); a less distinct terrace, which is seen in vertical section where the river gorge cuts it, to be composed of stratified gravels, the elevation of its summit being 99.6 feet; and again a beach-like ridge, the highest line on the front of the embankment, at 116 feet.

Series 11.—Coast east of Poplar River.—East of Poplar river two terraces are observed to follow the shore more or less continuously for some miles. Both are covered with timber, but as they are low and not usually distant from the shore, their topographic character is not obscured beyond recognition. Both are wave-cut terraces and have been carved out of a primary embankment which mantles the rocky slopes of the coast. These terraces were found to be susceptible of partial measurement at a fishermen's clearing about two miles from Poplar river. Here the brink of the lower terrace is 14.5 feet above

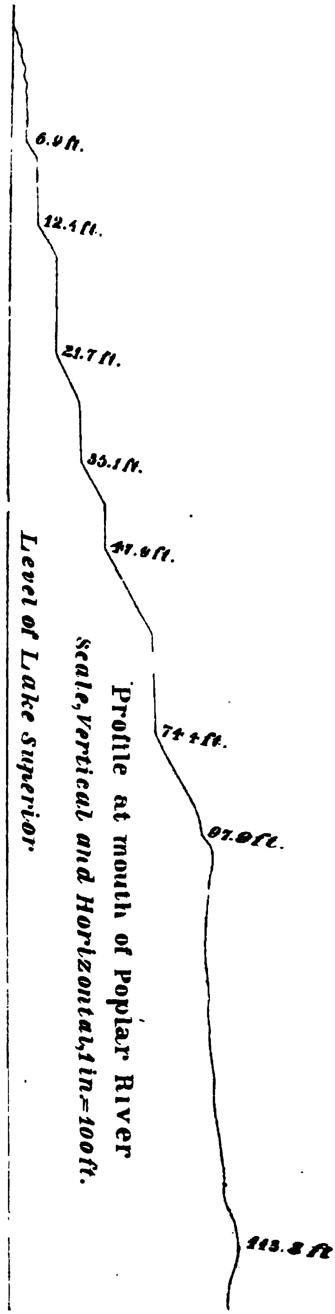


Fig. 10. Profile at mouth of Poplar river.

the lake, the front limit being a steep sea-cliff rising from the present shore. The terrace is 150 feet wide and at its rear has an elevation of 17.8 feet (III), thus exhibiting a slope of about 2 in 100. From the rear of this terrace an other sea cliff rises with a slope of 37 degrees and the brink of the second terrace is 37.5 feet above the lake. The terrace runs back under the beach apparently nearly flat. The elevation of its rear portion was estimated to be 6 feet higher than its brink, thus making the shore line about 43.5 feet (V) above the lake. The low sea-cliff which rises above the present shore and limits the lower terrace lakeward is rather a striking feature of this part of the shore, being a vertical scarp of the old embankment material resting upon rock varied in places by shorter stretches in which the cliff is wholly rock or wholly embankment gravel.

Series 12.—Good Harbor Bay.—The next locality along the coast where the ancient strand lines are sufficiently recognizable to be measured is at Good Harbor bay. The bay is open to the east and northeast and presents on the maps but a small jog in the generally uniform trend of the shore. The west side of the bay is overhung by a sea-cliff of very slightly inclined beds of red and brown shales and shaly sandstone which rises vertically to a hight of 15 feet. Between the base of the cliff and the shore line there is a narrow and low beach of shingle derived chiefly from the cliff. Above this sea-cliff there is a terrace about 100 feet wide and 20 feet high at its rear (III), which is thickly strewn with shingle. Immediately above this, with a low cliff between, is another terrace 25 feet wide and 27.2 feet high at its rear (IV), and also cut out of shingle and gravel. A third sea-cliff cut out of irregularly stratified gravels and sands of a primary embankment rises above this for about 50 feet. Above the summit of the cliff the ground rises gently in a rolling succession of beach-like ridges for several hundred feet horizontally and then grades into a distinct terrace abutting against the higher slopes of the hill at an elevation of 115.3 feet, (X).

Series 13.—Grand Marais.—The pinkish acid volcanic rocks of the vicinity of Grand Marais have by their mechanical disintegration along the sea-cliffs afforded an abundance of shingle and gravel with which the waves have banked up a fine series of beaches. These have been arranged in parallel ridges in the form of a beautifully distinct and typical wave-built terrace. As this terrace encroached upon the area of the lake the space between the shore and the rocky island upon which the lighthouse stands was spanned by a spit, and the construction of the terrace

was limited to the northeast side of the resulting bar, since the latter closed in a bay, the only entrance to which is by a deep channel between rocky points through which no shore drift could enter. [See Pl. XII, Fig. 1.] Within the bay at Grand Marais the wave action has been restricted, for lack of supply of new material, to working over the old material brought there before the bar was established; and its effect has been doubtless to extend the size of the bay and render it shallow. Within the bay the crest of the living beach has an altitude of 5.5 feet and is 23 feet distant from the water. Parallel to this and 65 feet farther inland across an intervening hollow is an old beach, the crest of which is 6.1 feet above the lake (I). Behind this is again a hollow and beyond the ground rises in two low steps to culminate in a third distinct and bare beach-crest at a distance 105 feet from the second. The altitude of this third beach is 12.1 feet (II). This is again followed landward by a parallel hollow, and again the ground rises (all bare shingle and gravel) in two low steps, each about 25 feet broad, the higher of which is 17 5 feet at its edge. Neither of these steps is taken to mark a definite stage of the water. The upper of these steps grades into a gently sloping wave-cut terrace 260 feet wide and 29.1 feet high at its rear. Thus from the back of this terrace (IV) to the present shore there appears to have been no sudden drop in the level of the lake but a gradual recession of the water. At stage IV the waves were cutting a terrace out of a pre-existent embankment of shingle and gravel. As the water sank the supply of drift from neighboring cliffs seems to have increased so that terrace-cutting gave way to terrace-building. The particular section selected for measurement shows the wave-built terrace at its narrowest part. Farther east it is many times broader.

Along the line of examintion the cutting action which produced the terrace of strand IV had eaten back into an embankment of shingle to the line of a beach of a former higher stage of the lake. For at the rear of the terrace a low sea-cliff of shingle rises with a slope of 28 degrees and this slope is nearly coincident with the front slope of a very distinct shingle beach with a hollow behind it, the crest of which is 43 6 feet above the lake (V). Above the level of this beach, the slope of the hill rises gently with an undulating profile, and presents a surface of gravel obscured by forest loam and shrubbery. In this vaguely undulating profile which was plotted to a large scale with great care, in the field, only two shore lines are distinctly registered, viz: one at an elevation of 55.9 feet (VI), in the form of a terrace 26 feet wide, and another at 113.5 feet (X), where the last of the gravel was observed.

Less than half a mile farther west, however, two still higher strand lines were observed and their altitudes measured. The lower of these is a terrace 127.3 feet high (XI) which is well seen from a distance towards evening, but which is less apparent at close quarters. The higher is a distinct but not an extensive gravel terrace encircling low glaciated domes of rock at an elevation of 162.6 feet (XV). This upper terrace is nearly on a level with the lower part of the bold bluff which overlooks Grand Marais on its southwest side. This bluff presents vertical walls from 20 to 50 feet high and was a sea-cliff when the water stood at the 162 6 foot level. On the east side of Grand Marais village a trail goes up over the hill. This was followed to the summit of the pass, about 750 feet above the lake, in search of higher strand lines. But although the trail passes almost continuously over morainic accumulations, no trace of a shore line was observed at levels higher than that last recorded.

Series 14.—Kimball's Creek—From Grand Marais eastward a low terrace, corresponding to strand line IV or the 29.1 feet terrac at Grand Marais, may be observed for several miles along the coast as far as Cow-tongue point. Higher traces of shore lines are doubtless present, but they are utterly obscured by the jungle. At the bottom of the bay below Cow-tongue point three terraces are observable from the lake, but only two of these could be located. The third eluded our search although it must have been covered by us in our excursion in quest of it near Kimball's creek; and the second was difficult to locate with precision on account of the lack of contrast between its slope and that of a pre-existent slope of rock in which no cliff had been carved. This terrace has a measured minimum elevation of 80.1 feet (VII), and its maximum is within two or three feet of this figure It is evidently neither a wave-cut nor a wave-built terrace, but might be classed as a current-built terrace. Below this is a flat clearing on which stands a half-breed's house. The flat is the first of the three terraces referred to. At its rear it is 28.5 feet high (IV), and above it rises a steeply inclined sea-cliff carved out of the primary embankment, whose upper surface constitutes the second terrace. Farther along the shore this terrace is again seen about a mile below Fish-hook point, and again below the mouth of Brulé river, where it is being cut into by the wave-action so as to present the scarp of a sea-cliff rising above the existing shore.

Series 15.—Horseshoe Bay.—At the bottom of Horseshoe bay there is a very remarkable and striking series of three beautifully developed beaches. The bay, as its name implies, is not long pro-

portionate to its width, but its shores converge towards the upper end and the wave action has been exceedingly energetic in consequence of this rapid convergence. Vertical cliffs of massive gabbro in the vicinity of the bay, particularly on its west side, where they rise to an elevation of 50 feet, have supplied the material of which the beaches are constructed. There is also a sparing admixture of glacial erratics. The remarkable feature about the beaches is that there is no shingle or gravel or any fine material whatever in their composition. They are strictly boulder beaches resembling ridges of cannon balls, although there are as many sub-angular boulders as rounded ones. [See Pl. VIII, Fig. 2.] The crest of the lowest of these beaches is only 20 feet horizontally distant from the present shore line and its crest is 11.9 feet (I) above the lake. The crest is strikingly horizontal and curves parallel to the contour of the shore. It may be the storm beach of the present stage of the water, but the size of the boulders which range on an average from 6 inches to 12 inches in diameter, suggest that the crest was built up when the water was somewhat higher than now. Behind this beach there is a slight depression and behind this the second boulder beach rises to an elevation along its crest of 17.6 feet (II). The distance between the two beaches from crest to crest is about 100 feet. The boulders of which this beach is composed do not on the average vary much from 12 inches in diameter. This second beach is again followed by the usual parallel hollow and behind this rises the third and most imposing beach of the three. The crest of the latter is 200 feet distant from that of the second beach and is 38.6 feet high (IV). The front of this beach is not a simple slope as is the case with the two lower beaches, but its profile shows a distinct step-like feature in its lower part such as may be some times seen in clear water on the subaqueous slope of some of the living beaches of the lake. The component boulders of this beach are perceptibly larger than those of the lower beaches, the average diameter being over 12 inches. Many were measured which greatly exceeded this dimension. This beach was clearly developed as a bar across the bay when the water was at stage IV, for behind the beach there is a broad expanse of marshy ground much lower than the beach, which represents the lagoon formed by the establishment of the beach bar. At higher elevations of the surface of the water, Horseshoe bay would have been merged with the common expanse of the lake and the shore carried further inland than the range of our observations.

Series 16.—Double Bay—A fine display of terrace topography, visible through the burnt and still standing timber, meets the view on entering Double bay. The present shore line is backed by a steep sea-cliff which is being carved out of an embankment which is probably fundamentally morainic, although modified in form by shore action of former high stages of the lake. Numerous boulders are worked out of the embankment and are strewn along the present shore, but it is largely also composed of clayey material. Stretching back from the brink of this sea-cliff is a nearly flat terrace, which is about a quarter of a mile broad, and which spans the entire breadth of the embayment. The rear of this terrace is about 32 feet above the lake (IV). Above it rises a second sea-cliff followed by another broad terrace similar to the first, having an altitude at its rear which measured 85.8 feet (VII). This second sea-cliff is not continuously distinct. Above it spreads out a broad sloping plain which varies in width, according to the topography of the rocky slope which here begins to emerge through the superincumbent embankment. Along the line of section measured, this terrace is about a half mile wide and abuts upon a rocky slope; the line of abutment is horizontal, and although no well-marked sea-cliff has been developed, owing to the resistant character of the rock, it may with great probability be taken to mark approximately a shore line. Its elevation, as measured is 160.5 feet (XIV). On top of this rocky ridge at an elevation of 278.9 feet, and at a distance inland of about a tenth of a mile from the rear of the last mentioned terrace was found a distinct gravel bar surrounding low rocky knolls and spanning the gaps between them. To the northeastward this beach appears to merge into a terrace which abuts upon the precipitous flanks of a spur of Farquhar's Knob. The rear of this terrace would be a few feet higher than the figures given for the elevation of the gravel bar, but its precise elevation was not determined. It doubtless corresponds to strand XXI.

Series 17.—Grand Portage—It was hoped from a distant inspection of the topography of the pass through the hills at Grand Portage, from its being fairly free from timber, and from its gentle grade, which renders the country accessible for some miles from shore within moderate limits of elevation, that the registration of the ancient strand lines of lake Superior would at this place be fuller than usual. This hope was, however, not fulfilled, and only a few of the strand lines were satisfactorily located by carrying a line of levels along the portage trail. From the nature of the em-

bayment in the hills it is evident at a glance that at the higher stages of the water Grand Portage bay must have extended several miles inland and have had a somewhat irregular shore contour with sharp indentations, particularly on its west side. From the precipitous character of the bluffs or promontories which limit the embayment on either side it is presumed that very little of the general shore drift found a lodgment in the bay, and whatever embankments may have accumulated would be of local derivation. The fact that the general shore drift did not find its way into the bay at the higher stages of the lake, either around Mt. Josephine on the east or the bold precipices which rise on the west of the embayment, is evidenced by the absence of such drift on the wave-cut terraces which contour these precipitous slopes on either hand, as will be noted later. In spite of this exclusion of the general shore drift, there is evidence that at probably all recorded stages of the water, the water was in the middle parts of the bay as it is now, always shallow, and that waves, although very effective on the neighboring steep slopes where the water was deep, left comparatively feeble traces of their action on the successive shores at the head of the bay. The conditions which have favored an excessive accumulation of local detritus in the bay and rendered it shallow from the highest stages of the lake down to the present are, (1) the presence of a massive morainic ridge crossing the valley about four miles north of the village, and, (2) a small stream cutting through it which has built up a succession of sloping delta plains, each of which has been cut through in turn as the level of the lake dropped. The higher and older delta plains appear to be much more extensive than the later, and it is a possible case that at the time of their building the stream flowed from beneath ice still lingering behind the moraine in the upper part of the valley. The highest delta forms a very distinct broad plain which has been terraced by the stream, but which cannot be clearly separated at its rear from the present front slope of the moraine. Half a mile or more in front of the moraine there projects through the plain a rocky glaciated dome a few hundred feet in diameter. The abutment of the plain upon the steep slopes of this island-like mass of bare rock is very sharp. An inspection of the surface of the rock, which is uneven in detail on top, warrants the belief that it was not submerged at the time of the formation of the plain which encircles it, and that it was, therefore, but little above the level of the water which conditioned the slope of the plain. The elevation of the plain at this point was measured at 339.7 feet, which altitude is placed in the table as representing approximately strand line XXVII.

A higher terrace was also observed abutting on a rocky slope at an elevation of 458 feet, but the brushy character of country obscured its relation to that just mentioned and it could not be determined to be distinct from it.

Further down the valley on a lower delta slope are two low beach-like ridges, one at 254.7 feet (XX), and another at 231.8 feet (XVIII), which appear to have been barriers thrown up by the breakers in a shallow bay at some distance from the shore and similar to the barrier which is now forming in Grand Portage bay. On a still lower delta plain and much nearer the lake is still another low barrier ridge which has an elevation of 103.5 feet (IX). The church of the village stands on a terrace which, at its rear, at the foot of a low and worn-down cliff carved out of delta material, is 74.7 feet high (VII). Immediately to the lakeward side of the church the ground drops steeply to the level of the terrace on which the village is built. This drop represents a sea-cliff which is one of the most striking shore features of Grand Portage. The terrace which extends out from its base is 37.9 feet above the lake (IV). There is still a lower terrace the rear of which is about 8.6 feet above the lake (I). The present bay is shallow out as far as Grand Portage island so that the waves break before reaching shore; and one of the results of this is the development of a subaqueous ridge or barrier parallel with the shore line. Boats drawing over a foot of water may ground on this barrier, but between it and the shore the water is deeper. The barrier as yet appears nowhere above the surface of the lake and probably it will never so develop into a barrier beach, but always remain subaqueous since heavy storm waves necessary for the throwing up of the initial subaerial ridge can not reach this line on account of the lakeward shoal.

Series 18.—Mount Josephine. The south side of Mt. Josephine presents a succession of strand lines most of which are exceptionally well defined. The mountain is a ridge about 800 feet high and consists of a great dyke of gabbro or diabase, to both of the steep flanks of which a selvage of southerly dipping slates and quartzite of the Animikie is still adhering up to varying elevations. The extremity of the ridge juts out into the lake as a sharp point which forms the eastern limit of Grand Portage bay and is known as Hat point. The most striking and most heavily scored of the strand lines is a wave cut terrace (XXX) which contours the side of the ridge at an elevation of 509.5 feet and sweeps around in a beautifully shaped curve where the ridge abuts upon the main mass of rock from which it is a spur. The timber has

been burnt over a portion of the hillside so that the character of the terrace, as a heavily cut shelf, perfectly horizontal, projected against the side of the hill, attracts the eye from a long way off, and excites the curiosity of even the casual observer as a peculiar feature of the landscape. At close quarters the terrace was found to be about 100 feet wide, to have a gentle lakeward slope for this distance, and then to drop away into a steep declivity of the hillside. At its rear rises a steep cliff which is partly the side of the great dyke, partly the indurated slates adhering to the dyke, and partly a wall of the dyke rock, farther in than its original side wall, which has been established by the cutting action at the level of the terrace. The terrace is strewn with great blocks which have fallen from the vertical cliff, and at one place a considerable talus has accumulated in great part since the wave-action ceased. There is a considerable proportion of glacial drift over the lower flanks of the ridge and this seems to have extended up to the summit of the ridge since there are some northern erratics strewn over the surface of the terrace. It is possible that the terrace may in part, particularly at its northern end, be cut out of a morainic dump. The summit of Mt. Josephine is heavily glaciated. A small portion of beach shingle and gravel is strewn over the surface of the terrace. The possibility of the terrace being a feature of differential degradation was critically considered on the ground but all the evidence observed made clearly for its wave wrought origin. The facts that the strata dip southerly while the rear of the terrace is horizontal, that the slope of the terrace is outward and independent of the dip, and that the terrace character is maintained where it swings in the curve of the ——— away from the line of the dyke, indicate at once that its form and situation are not conditioned by the structure of the rocks. The terrace is further interesting as yielding to accurate measurement figures for its altitude which are identical with those obtained for the equally well-defined strand line (series 3) at Hardy's schoolhouse in East Duluth.

This terrace, although the most pronounced of the dents in the west side of Mt. Josephine, is not the highest. There are two higher and presumably older terraces, neither of which is so extensive along the hillside nor so wide. Both of these are much alike in their general character, and in the measure of their extent and they rise one above the other. They are continuous for only a few hundred yards and both vary from about 30 to 50 feet in width. Both are backed by a sea-cliff and both are strewn with blocks of rocks derived from it and from drift accumulations.

These terraces are respectively 587.2 feet (XXXII) and 607.3 feet (XXXIII) above the lake. One of them is a prominent feature of the hillside as a distinct horizontal shelf visible at long distance; the other is not so apparent, owing, doubtless, to the thickened shrubbery. It is suggested in explanation of their short extent, that they lie in a slight embayment on the side of this ridge and so somewhat protected; while their continuation on the more salient portions of the ridge has been undermined and cut away by the same wave action which resulted in the devlopment of the broader terrace at 509 feet. These two terraces at 587 feet and 607 feet are remarkable for being the highest strand lines which have thus far been observed on the coast of lake Superior.

Lower on the same slope of Mt. Josephine are two other sharply scored but narrow terraces which lie well within the unburnt timber and which are therefore not apparent at a distance. The first of them in descending order is at an elevation of 313.5 feet (XXII) and the second at 226.1 feet (XVIII). Both are readily observable on the trail which crosses Mt. Josephine from Grand Portage to Wauswaugoning bay, and both appear to be cut out of the accumulation of drift which here mantles the rocky base of the ridge. Still further down at the base of the hill is a boulder beach (V) the crest of which is 43 feet above the lake; and between this and the shore there is again a drop in the general slope to an even terrace which is 19.9 feet (III) high at its rear, and which extends for less than 100 yards to the brink of the sea-cliff of the present shore. This last sea-cliff has a hight of 13 feet.

Series 19.—Wauswaugoning Bay.—Wauswaugoning bay is limited on the southwest side by Hat point and on the northeast by the base of Pigeon point. The shore along the side of Hat point is a precipitous cliff without a beach or visible shelf at its base, and the water is deep. This line of high cliff, rising in places to a hight of 800 feet, is continuous around the embayment, but leaves the shore line about half way from the extremity of the point and sweeps round to the vicinity of Pigeon falls roughly parallel to the shore, but usually several hundred yards distant from it. At the base of Pigeon point the ground is low, and at higher stages of the water Pigeon point was either an island or was completely submerged so that portion of the sediment of Pigeon river then found its way into Wauswaugoning bay. But as Pigeon river is a new stream, being a succession of cataracts and stretches of still water, the sediment is small in quantity and very fine so that it supplied practically no material which would remain in the zone of shore drift on a wave-beaten shore. Its sediments have

taken the form of a delta at the head of Pigeon bay where protected from wave action. The Pigeon river is clearly a very recent drainage and it seems probable that the ancient outlet was into Grand Portage bay. This dearth of stream detritus has characterized the shores of Wauswaugoning bay at all stages of lake Superior, there being no other stream cutting through or tumbling over the cliffs which rise around it. In this respect the bay presents a marked contrast to the neighboring bay at Grand Portage with its heavy deltas. The contrast between the two bays is perhaps best seen in the character of the strand line registrations. The higher stages of the lake were not strongly registered at the head of Grand Portage bay because of the lack of contrast between the subaerial and subaqueous slopes of the delta. At the head of Wauswaugoning bay the water line of the higher stage was not registered at all, because the shore was along the face of vertical cliffs of pre-lacustrine origin. As the lake subsided the water surface reached the talus of the cliffs and terrace lines were doubtless carved. But in the vicinity of the cliffs the growth of the talus since the water subsided has rendered them unrecognizable; and it is only when we come to comparitively low stages of the lake, where on the gentler slopes of the talus, conditions have been favorable for the carrying of a bar across the head of the bay, that permanent strand lines have been established. These bars form two magnificent beach embankments with lagoon hollow behind and undulatory slope in front. They are composed entirely of coarse shingle of quartzyte and hard siliceous slate which mostly weather red. The vegetation has been burnt off and the crests are remarkably sharp and continuously horizontal lines, which by their color and distinctness give a striking character to the landscape. The upper of these two beaches is 76.5 feet (VII) above the lake and the lower 43.7 feet (V).

Series 20.—Near Birch Island.—Outside of Wauswaugoning bay on the south side of Pigeon point and about half a mile east of Birch island there is a fine display of storm beaches. The material of which they are built is the detritus of the reddish Animikie quartzyte which is the prevalent rock on this part of the coast. The shore is well exposed to southerly winds. The beaches although well developed are here only found at comparatively low altitudes, there being no high slopes upon which embankments of higher stages of the lake could be lodged. Three distinct beach crests rise one above the other all having the same general character. The first of these is within reach of the waves of the present stage of the lake and is possibly the living storm beach in

process of growth or having attained its maximum growth. Its crest is sharp and uniformily level at 13.6 feet above still water (I). About 150 feet from this crest rises the second beach equally sharp and distinct, with an elevation of 17.4 (II). On the front slope of this beach is a subordinate shelf-like feature. There is no perceptible depression in the 150 feet of space between the two beach lines. The third beach crest is about 100 feet behind the second and there is a slight depression between the two. There is a depression behind the third beach, *i.e.*, between it and the rocky slope upon which it has been banked up. The third beach has an elevation of 21 feet (III). All three beaches are, like those of series 19, absolutely devoid of soil or fine material of any kind. There is no blown sand to obscure their characters as perfect wave-built embankments of shingle and gravel spanning the bay between two rocky ridges.

Series 21.—Pigeon Point.—From the abandoned ranch at the mouth of Pigeon river a trail crosses Pigeon point to the shore on the south side. This trail is transverse to the trend of the rocks and between the two main ridges is an embayment which opens to the south-east on the south side of the point. The trail in crossing this embayment follows the crest of a shingle beach which spans it. The total length of the beach is something less than one-eighth of a mile, there is no breach in it and behind it is a well defined lagoon hollow. The crest of the beach was found to have an elevation of 75.6 feet (VII). On the front of the embankment which culminates in this beach a second beach has been developed at an altitude of 56.6 feet (VI). It is probable that several other beaches lie between this and the shore, but the interval is heavily timbered and definite results are scarcely obtainable.

Series 22.—Pigeon River.—At the mouth of Pigeon river, on the Canadian side, there are three fairly distinct traces of shore action. They are found on the south side of the point of land which separates the canon of the Pigeon from Pigeon bay. The highest is of the nature of a short gravel bar, connecting two projecting masses of rock. It is about one foot lower in its middle than at the sides where it abuts upon the rock. Its elevation at the latter place was found to be 134.3 feet (XII). The fine character of the gravel (mostly of slate), and the low curvature of the bar indicates development under sheltered conditions, such as the local topography would suggest. On the lower flanks of the hillside are two distinct terraces, one at 60.8 feet (VI) and another at 18.2 feet (III), both of which are probably rather to be strictly interpreted as stream

terraces of the Pigeon, but being at its mouth and below rapid water, they represent very closely the stages of the lake at which they were developed.

Series 23 —McKellar's Point.—The south side of McKellar's point near its extremity, has afforded conditions eminently favorable for the accumulation of a series of shingle beaches, viz: A cove between rocky bluffs, high sea-cliffs on either side shedding fragments of quartzyte, hard slate and trap through various successive stages of the lake, and exposure to the full sweep of the lake from the south. The fact that the beaches have accumulated on one side of a narrow ridge-like promontory has insured them from intersection by drainage lines and thus they are remarkably perfect in form. They have been protected also by forest growths but these have recently been removed by fire up to about 100 feet above the lake, leaving the bare red banks of shingle and boulders. It is quite noticeable in comparing the different beaches of the series that the material composing the higher ones is coarser than that of the lower. In the higher beaches, the embankment is made up essentially of boulders in which the flattened shingle character is comparatively rare. They are mostly subangular and have an average diameter of over six inches according to deliberate estimate made on the ground. There is in these higher beaches nothing which might be termed gravel. In the lower beaches the shingle-like character of the drift is pronounced. Some of the higher beach accumulations have been cut into by the wave action at lower stages, so that a part of the old material of the higher beaches has been worked over in successive zones of shore attrition. It is possible that the lower accumulations may be mostly composed of material derived from the older and higher accumulations, and if so, the contrast in form and size of the pebbles would be accounted for. The same contrast in the character of the beach material was observed on Wauswaugoning bay though to a less marked degree.

The series of strand lines on McKellar's point is divisible into three parts. The highest is a boulder beach that spans the embayment at an elevation of 137.6 feet (XII). Between this and the next beach there is an interval of perhaps two hundred yards in which no distinct shore lines were observed. This beach constitutes the first of the three divisons of the series and seems to be distinct from those which follow. At about 100 feet altitude we come well within the burnt timber and at the same time upon the second division of our series. This division consists of a continuous succession of beaches extending over a horizontal distance of about 300 feet. The actual figures obtained by levelling were for

the highest of the succession 101.4 feet (IX) and for the lowest 82.2 feet (VII). Between the two beaches at these respective elevations, there are three distinct intermediate ridges, of which the middle one is perhaps the most pronounced and has an elevation of 89.7 feet (VIII). The succession seems to indicate, without question, a gradual recession of the lake between stages IX and VII. Whether this gradual recession continued below VII or not cannot be inferred from the record of this series. For, at a lower level the lake, whether arrived at by a gradual subsidence or by a sudden drop, conditions of shore action were so changed that instead of wave-building wave-cutting set in. This resulted in the development of a distinct wave-cut terrace and corresponding sea-cliff, both carved out of the pebble embankment. The terrace is about 100 feet wide and the sea-cliff is 25 feet high, and rises with as steep a slope as it is possible for the loose material of the embankment to lie. The rear of the terrace was found to be 48.4 feet above the lake and seems to represent stage V. This sea-cliff and the shore features below it constitute the third division of our series of strand lines. On the front part of this terrace there has been built up a distinct but low beach or barrier ridge which has an elevation of 36.3 feet (IV). The front limit of the terrace is again a cliff, almost vertical in places and carved out of shingle. At the base of the cliff is a beach accumulation which seems to be the beginning of a wave-built terrace. The terrace effect is somewhat marked, although the embankment is narrow. The maximum elevation of the embankment at the foot of the shingle cliff is 8.4 feet (I) and it is within easy range of storm waves of the present lake.

Series 24.—Thompson Island.—On Thompson island there are three strand lines recognizable. Two of them are shingle beaches and the third is a line of wave wrought caves on the south side of the island. The island is a long narrow ridge composed of a great trap dyke with some subordinate dykes running parallel to it and blocks of horizontal strata lying between the dykes or adhering to their sides. The upper of the two beaches lies on the summit of the main dyke at about the highest point of the east end of the island. The altitude of its crest is 97 feet (IX). The lower beach is at the extreme east end of the island. Its crest was found to be 28.7 feet above the lake (IV). Both beaches are composed of clean shingle and pebbles free of all fine material and unobscured by soil. The development of caves on the face of the nearly vertical side of the main dyke seems to have been primarily conditioned by weak spots in the rock due to the inclusion of

masses of slate in the trap. The occurrence of a series of them at the same level and having the same general character as some smaller caves developed on the present shore can only be referred to shore action. The caves are widest at the mouth and at the bottom; and the sides converge rapidly inward and upward. Those examined were about 20 to 25 feet in length, and were about 12 to 15 feet high, at their entrance. The floors sloped outward. After comparing them with similiar cavities on the present shore line a point was selected in the floor of one of these caves as representing most probably the water level, and it was found by measurement to be 45.6 feet above the lake (V).

Series 25.—Shore opposite Flat Island.—The trap capped cliffs of hard slaty sandstones which are so characteristic of the topography of Thunder bay have at all stages of the lake afforded an abundant supply of durable shingle, and the fact that only a small number of beach accumulations have been observed on the talus slopes of these cliffs is due to the presence of the timber which obscures them from view. Wherever conditions are favorable on this part of the coast for observation, by reason of fire having removed the timber, or by reason of such talus slopes being within a short distance of the present shore, the beaches are observable. On the shore opposite Flat island there is a set of three beaches which are entirely analagous to those described on McKellar's point. They have been built up on the talus which encircles a sharp projecting angle in a line of vertical escarpment. At the summit of the series is a great beach ridge whose normal hight was found to be about 105 feet (IX), but which at one place is somewhat higher and is irregular in its form, as if the effect of the storms at this projecting point had been exceptionally great. This higher part has a maximum hight of 109.2 feet. From this great beach ridge a continuous succession of later beaches extends down to a beach crest which has an elevation of 86.4 feet (VII). The intervening beaches are sometimes distinct and sometimes run into one another. They seem clearly to indicate, just as the beaches at McKellar's point do, a gradual recession of the waters of the lake through this distance. Below this lower beach there is again as at McKellar's point, a precipitous, here nearly vertical, sea-cliff carved out of the shingle. At the base of the cliff a broad sloping terrace extends out to the present shore. The rear of this terrace at the base of the cliff is found to have an elevation of 45.3 feet (V). On the front part of this terrace at a distance of 150 feet from the present shore is a low barrier beach, the crest of which is 8.8 feet above the lake (I). The entire series is well

bared and the beaches above the sea-cliff are destitute of all vegetation and soil. The sea-cliff is remarkable for its precipitous, wall-like character, while composed of loose shingle. There is no cementing material whatever and the broad flat character of the shingle alone enables the cliff to maintain its form.

Series 26.—Shore above Carp river.—In the embayment of the coast next above that into which Carp river flows, the country has been burnt over partially, revealing some fine shingle beaches at the head of the embayment. These cannot be seen from the shore but may be viewed to advantage from a boat some distance out on the lake. They are about half a mile inland from the present shore. The embayment within which they lie is bounded by vertical walls of columnar trap resting on flat Animikie slate, the two walls converging and meeting at the head of the embayment. On the sides of this embayment, at the immediate base of the cliffs, is the remnant of a terrace which appears to be nearly flat and which was found to have an elevation of 164.1 feet (XIV). The terrace is composed of shingle and gravel with cliff debris much less water worn. Below this and spanning the embayment from cliff to cliff is a great embankment of shingle the summit of which is a perfect beach. The distance between the canon walls along the line of the embankment is not more than a quarter of a mile. There is no breach whatever in the embankment. Behind the beach, *i. e.*, between it and the talus of the cliffs which encircle the head of the embayment is a very pronounced lagoon hollow, the bottom of which is about ten feet lower than the crest line of the beach. The crest of the beach is 138.2 feet above the lake (XII). Against the front slope of this great embankment another beach also of large dimensions has been built at a lower stage of the lake. Its crest has an elevation of 122.5 feet (XI). A little below this at an elevation of 116.8 feet is another, but feebly developed beach which probably also indicates a distinct though short-lived stage of the water. The conditions of the embayment are, it is perhaps needless, to say, peculiarly favorable for the development of such embankments. The continuous line of cliffs, of which the embayment is but an indentation, would, below the base of the trap cap, shed a large amount of fairly hard but slaty Animikie sandstone for the formation of the shingle, which, traveling along the shore, from either quarter, would be entrapped in the embayment. The latter is in ground-plan, funnel-shaped, opening upon the lake and exposed to northeasterly storms.

Series 27.—Carp river.—The sides of the canon through which the overflow of Loch Lomond finds way to lake Superior by the short succession of rapids known as Carp river, contains numerous registrations of old strands, which are for the most part clearly defined. The canon is funnel-shaped, and has been an embayment at all the known stages of the lake. A wagon road ascends the canon to the level of Loch Lomond, a distance of about two miles, which renders the inspection of the topography of the canon an easy matter. Rising immediately from the present shore line there is a rolling succession of small, ill-defined gravel beaches at low levels which were not regarded as altogether simple in their development, but probably as having been modified by the stream which emerges at this point. They seem, however, to indicate a gradual recession of the water without leaving an emphasis at any one stage to suggest its longer continuance than its associate stages. The first well-defined beach has an elevation along its crest of 33.8 feet. (IV). This is followed by another great beach of perfect form at an elevation of 52.1 feet. (V). Above this are two terraces flanking the south side of the canon, one at 82.1 feet (VII) above the lake, and the other at 106.3 feet.(IX). Both are evidently current-built terraces and may owe their origin to stream action: but as their situation is near the mouth of the canon, their level corresponds very closely to that of the lake at the stages when they were built, unless the stream had a delta extending far out into the lake, a feature of which there is no evidence and which is highly improbable at the mouth of so short a stream arising from the overflow of a clear water lake. Further up the road is another great gravel beach which has been built up on the gently sloping surface of a great accumulation of stratified gravel which has once filled the canon, but is now cut through by the stream to bedrock again. The crest of the beach at the point leveled was 139.8 feet (XII) above the lake. The section afforded by the sides of the stream trench shows gravels to a thickness of nearly one hundred feet and proves that the canon as a feature of stream erosion antedates the high levels of the lake. Above this, on the north side of the canon, there are three small terraces, doubtless again essentially stream built, but also as argued above, representing closely levels of lake Superior. They were found to have the following elevations by our measurements, viz.: 221.8 feet (XVIII), 256.4 feet (XX), 288.1 feet XXI.

Series 28—Pie Island—The "Pie" of Pie island is a magnificent example of the *mesa* topography which is so characteristic of Thunder bay scenery. A roughly circular area of columnar trap,

the remnant of a once extensive sheet, lies horizontally upon the flat Animikie slates. The edge of the trap, together with that portion of the slate which intervenes between it and the summit of the talus, presents vertical walls several hundred feet high. The top of the "Pie" is about 850 feet above the lake. This mesa was surrounded by waters of the lake at its higher stages beyond the general upper limit of the talus, and it is doubtless encircled by corresponding beaches and terraces on the slopes beneath the timber. There are strong suggestions of such features which even the timber cannot obscure. On the west side of the island the ground has been cleared and cultivated, and here on Mr. Keefer's ranch some of the strand lines stand out clearly and attract the eye at a distance of many miles. There are three of them which were sufficiently distinct at close quarters to permit of precise location. The highest of these is a broad terrace abutting upon the talus of the "Pie." It has the form of a great spit, the rear of which is 221.5 feet (XVIII) above the lake. It seems to be essentially a current-built structure, and there is no wave-built beach at its highest part, the material of the terrace being mostly fine gravel and broken shale. The crest or axial line of the spit, however, slopes downward or lakeward and seems to have been a salient of the shore line at various lower stages, at which its construction was continued, and upon the sides of which true beaches were thrown up. The profile, both along the axial line and transverse to it, is undulatory while regularly descending. Among several somewhat vaguely defined beaches which contour this complexly built spit, there is one very fine shingle beach which leaves nothing to be desired in the perfection of its form, its linear continuity, and its state of preservation. The crest of this beach was found to be 136.5 feet (XII) above the lake by our levels.

The third strand line is a broad terrace which along the line of our measurement abuts against a talus of great angular blocks of trap. Here it has an elevation of 43.5 feet (V) and slopes away from this altitude, without any marked break, to the low cliff above the present shore, in the vicinity of Mr. Keefer's house. More patient examination of the talus slopes of Pie island where the timber is thin, would doubtless reveal many other strands.

*Series 29.—Brulé Point.**—There is but one strand in this series, the coast being comparatively low. It consists of a well defined shingle and pebble beach in a small bay on the west side of the point. The crest of the beach was found to be 34.7 feet (IV)

*By an error printed Brulé *river* in the table.

above the lake. This beach seems to be correlative with a broad terrace which extends far inland and which could not in the time given to the inquiry be discriminated from the plain of Kaministiquia delta. This delta has been developed at various successively lower stages of the lake and would require careful and very critical examination in order to win from it any record of definite and prolonged stages of its base level.

Series 30.–Kaministiquia.—At the higher stages of lake Superior a large stream swept down the valley of the present Kaministiquia. At Kaministiquia station on the Canadian Pacific, this valley is constricted by the approximation of rocky hills which rise nearly 500 feet above the level of the railway at this point. Immediately below the station the valley begins to open out and continues wide and open to lake Superior. This narrow place in the valley seems to have been the head of the delta plain of the ancient stream. There is a gravel pit close to the railway station which reveals gravel and sand in false bedded attitudes. The pit presents a section of a very extensive terrace which appears to be the remnant of the old delta plain. This terrace adheres to the east side of the valley, the river in cutting its way down through it in pursuit of its steadily lowering base level having clung to the west side of the valley. But with such an open valley it seems probable that the waters of the lake which conditioned the apex of the delta were not far distant and that the level of the terrace at its abutment against the rocky slopes of the cañon indicate approximately the maximum figures for an altitude of one stage of the lake. The level of the terrace was found to be 455.1 feet above lake Superior. It is placed in the table as indicating a distinct stage of the lake (XXVIII) with considerable hesitation. It is not improbable that it should more properly be correlated with strand line XXVII.

Series 31.—Port Arthur.—In this series are some of the most beautiful terraces which have been noted among the strand lines of the north side of lake Superior. The series is also unique in comprising a well developed "*hooked spit.*" The effect of the terraces is strongly accentuated by the culture which has been imposed upon them. They are seen to best advantage, perhaps, within the town limits of Port Arthur, which is not yet so thickly built up as to obscure their character. [See Pl. IX. Fig. 1.] The lowest terrace is that upon which the business portion of the town is built. Its rear ends sharply at the base of a sea-cliff and was found to have an elevation of 61.4 feet (VI). From this altitude it slopes gently though not quite uniformily to the present shore through a distance in the heart of the town of about a quarter of a mile or less.

FIG. 1. TERRACE IN TOWN OF PORT ARTHUR. STREET ABOUT SIXTY FEET ABOVE THE LAKE. (P. 262.)

FIG. 2. PROFILE OF TERRACES AT BACK OF THUNDER CAPE. FROM SAWYER'S BAY. (P. 199.)

The next terrace is that upon which stands several of the churches of the town, the court house, and many of the more prominent residences. It has a very sharp brink at the upper limit of the sea-cliff above referred to and is on an average less than half as wide as the terrace below it. Its rear is also remarkably sharp in its abutment upon its limiting sea-cliff. This sea-cliff is for the most part composed of the loose material of an earlier embankment, but in one place it is a precipitous wall of rock. The rear of this terrace was found by our levels to have an altitude of 89.8 feet (VIII). Above this are two remnants of higher terraces, one at 95.7 feet (IX) and the other at 118.4 feet (X), which, though narrow and not so sharply defined as the lower ones, appear as quite sharp and distinct lines when viewed from a distance. There is still another narrow terrace at 148.8 feet (XIII) which is rather illy defined and is not noticeable at a distance.

At the brink of the hill behind the town a little to the south of the Dawson road is a gravel pit which affords an admirable section of a beach. The beach crest runs out from a shoulder of the hill at the entrance to the valley of the Kaministiquia. The beach has been a spit which tended to continue its growth in the direction of the shore line from whence it received its material and so attempted to span the valley. Its extremity was, however, soon swung around so as to point up the valley, or bay as it was at the stage of the lake. In this way the characteristic form of a "hook" was developed and the form is perfectly preserved. The spit beach is somewhat remarkable for the number of large boulders which are strewn over its surface, while its section in the gravel pit shows it to be chiefly made up of comparatively fine gravel. The crest of the beach, at a point close to the base of the spit is 170.1 feet above the lake (XV). Its extent indicates a long continued stage of the lake.

Series 32—McKenzie—From McKenzie station, about 14 miles east of Port Arthur on the Canadian Pacific railway, a series of terraces can be seen scoring the hills to the north at a distance of probably a little more than a mile and a half to the farthest. An effort was made to locate these terraces by running a line of levels from the railway, but this only met with partial success. The terraces which appeared so sharp and unequivocal from the railway station lost their character when approached closely, and could only be recognized as terraces with considerable doubt. Some of these terraces, also, were of so remarkable a character that although figures for their elevations were obtained, they could not without more critical study be identified as strand lines of lake

Superior. Indeed only the broad sandy terraces immediately to the north of the railway, the lowest of the series, was found to possess sufficient of the character and definition of shore topography to warrant its being regarded as a strand. And even here the question had to be carefully considered whether it was not a flood-plain of the stream which traverses it, and the cliff at its rear a stream cliff. The material of which the terrace is composed, a stratified sand, seemed to indicate that it was not a flood-plain, but the bottom of a shallow bay of the lake, which the configuration of the hills suggests. Sections of the plain are well revealed in the cuttings and sand pits at McKenzie. This plain was found to be susceptible of very precise measurement. At McKenzie station it is 320.4 feet above the lake, and at its rear along the base of the cliff nearly a half a mile distant, it has an elevation of 326.8 feet (XXIII.) Above this are two shelf-like portions of the profile which suggest terraces, but the smallness of the one and the irregular surface of the other, render them doubtful as features due to shore action. The elevations of these are respectively 347 feet and 379 feet above the lake. Still higher is a much more distinct terrace at 420 feet above the lake, which would be interpreted as a wave-cut terrace were it not that, at its rear part, immediately in front of the cliff which rises above it, there are several very remarkable pits or kettle holes without apparent drainage outlet. The kettle holes have clearly originated after the development of the plain of the terrace. The pits were 15 feet to 20 feet deep, and irregularly funnel-shaped, and could apparently have been formed only by local subsidence of the ground. About 40 feet above this terrace, ascending the cliff at its rear, we come upon the brink of a much more extensive terrace-plain which is also backed by apparent sea-cliffs. The front of this terrace has an elevation of 460 feet, and its rear 497 feet with a slope of 37 feet in about a half a mile. When viewed on a level the plain presents a uniform, apparently flat surface. Immediately that the eye rises above it, however, it is discovered to be pitted over its entire extent by kettle holes which are similar to those noted on the plain below, but which are much larger and relatively to the area much more numerous. In many cases two pits are so close together that the narrow ridge separating them is quite wedge-like and has frequently broken down. The pits are so numerous that it is not practicable to traverse the plain in any direction in a straight line, but only to wind in and out on the narrow remnants of the original plain which are left between the pits. The sides of the pits are in many cases as steep as the material can lie. The material is

morainic in character and contains numerous huge boulders. In some cases these large boulders were conspicuous features in the narrow bottoms of the pits. Here again the only suggestion that could be obtained after traversing the plain several times was that the pits were posterior in their origin to that of the plain. Above this remarkable pitted plain is another important terrace also composed of coarse morainic material, but not apparently pitted so far as observations could be made. This terrace is thickly wooded while the lower ground is burned off. On account of the brush it could not be examined easily, but it appeared to slope toward the rocky hillside of the valley, and although this appearance was not verified, it suggested, when taken into connection with the character of the material of which it was composed, the possibility that the feature was a true morainic terrace.*

A definite explanation of the mode of development of these interesting terraces is not possible from the scant study which the writer was able to give them. He can only commend them to students of topographic forms as an interesting field for study which is easily accessible. A tentative suggestion may, however, be not out of place. These terraces occupy the sides of a valley which was unquestionably filled with the continental ice sheet. As the front of the sheet receded this valley was very probably occupied by an ice current running out from the general body of the glacier, or it may possibly have been occupied still later by a local alpine glacier. The configuration of the hills would favor such a possibility. Students of the kettle moraine have come to the conclusion that the kettle-holes of that region have been formed by the burial of masses of ice within the moraine which afterward melted and caused the surface to collapse. There is an immense accumulation of morainic material in the valley we are considering. Is it possible that such accumulations contained numerous buried blocks of ice, which continued frozen until after the high stages of the lake had cut broad terraces out of the moraine? If the high stages of the lake followed closely upon the recession of the ice front, it seems not impossible, when we consider the low temperature which lake Superior maintaines even to this day.

Series 33.—East side of Thunder Bay.—The east side of Thunder bay from its upper end to Sawyer's bay presents a very bold and remarkably straight cliff several hundred feet high composed of Keweenian sandstone resting in Animikie slate, both flat bedded

*cf. Gilbert, Lake Bonneville, p. 81.

and in apparent conformity. The cliff is probably originally and genetically a fault scarp. In the face of the cliff there has been cut a distinct shelf or terrace, the rear of which, at the foot of a talus due largely to sub-aerial degradation, was found to be 57.5 feet (VI). The shelf is assumed to be, in part at least, a wave-cut terrace.

A similar terrace is being cut at the present level of the lake, causing the recession of the lower cliff, so that it is apparent that the shelf referred to must have been once wider than it now appears.

Series 34.—Back of Thunder Cape.—At the back of Thunder cape, on the south side of the entrance to Sawyer's bay, there has been preserved a series of wave-cut terraces and sea-cliffs which are of unusual interest for the perfection of their form and for the fact that being situated on a projecting portion of the coast they are revealed in sharp and distinct profile to certain points of view. The profile was photographed and is reproduced in plate IX, figure 2, the view selected being that obtained from the north side of Sawyer's bay. All of these terraces have been cut out of Animikie slates and present very sharp sea-cliffs particularly as regards the lower members of the series, where the cliffs are nearly vertical scarps which can only be scaled at certain favorable localities. The timber has been burnt so that their characters are unobscured. The first four of these terraces have a fairly uniform width which does not vary much from 100 feet, and all have the usual lakeward slope. The figures obtained for the elevations of these, at the base of their limiting sea-cliffs, are respectively 49.6 feet (V), 122 feet (XI), 170 feet (XV) and 261.2 feet (XX). The fifth terrace is smaller and has an elevation of 288.4 feet (XXI). The sixth terrace breaks down in its front part into a broad uneven plain when examined closely, but when viewed from a distance affords the simple profile of a continuous slope. Its altitude is 392.3 feet (XXV). Above this there is still another broad terrace, the rear of which was found to be at a point representing its sharpest features, 482.2 feet. This terrace slopes, however, rather rapidly, is more obscured by timber and could not be definitely recognized as of wave-wrought origin. It was therefore not placed in the table although there is a probability of its being a strand line. At its rear is a talus accumulation from cliffs of trap rock which rise high above it.

Series 35.—Silver Islet.—On the trail from the deserted village at Silver islet to lake Marie Louise an interesting series of beaches may be conveniently examined. The series is chiefly interesting

for the great number of beaches which are found within a very limited vertical range. The crest of the present storm beach is 12 feet above the level of the lake. Between this and a beach the crest of which is 39.3 feet above the lake, there are no less than nine distinct well formed shingle beach ridges rising one above another on a gentle slope. The first two of these are somewhat larger and apparently of more importance than the others and are placed in the table at stages II and III, the elevation of their respective crests being 14.7 feet and 20.5 feet. The elevations obtained for the crests of the other shingle ridges are as follows: 21.4 feet, 23.2 feet, 25.9 feet, 26.7 feet, 31 feet, 33.7 feet, and 36.8 feet. If projected on a vertical plane these beaches, eleven in all, would appear closely crowded, but in reality, owing to the gentle slope upon which they have been built, they are spaced horizontally so as to be well individualized and spread over several hundred yards of ground in a direction transverse to their trend.

This portion of the series, only certain dominant members of which have been inserted in the table, clearly indicates a gradual recession of the lake, from the stage at which the 39.3 feet (IV) beach was built down to the present level.

At this level the beaches cease and the next indication of a strand line is a terrace at 59.2 feet (VI) with a low and rather ill-defined cliff at its rear. The next is an isolated beach resting on a rocky slope the crest of which is 89.2 feet (VIII) above the lake on the line of the trail. In ascending the trail we next come upon a beach at 136.7 feet (XII) which is the lowest of a continuous succession of beaches extending for a distance of about 600 feet. The highest has along its crest an elevation of 149.2 feet (XIII). This succession of beach ridges has practically the character of a wave-built terrace with this exception, that the stage of the water has not been constant but has been very slightly lower for each successive ridge of the terrace. From the upper beach of this nearly horizontal succession of beach ridges there is another succession which rises more rapidly and which is fewer in number. The upper member of this succession is a beach the crest of which is 168.2 feet (XV). Here then we have evidence of a gradual recession of the lake from stage XV to stage XII or from 168.2 feet to 136.7 feet. The beach which represents stage XV (168.2 feet) is also the highest point of the trail along that portion of it on which strand lines are observable. In other words, the beach is an old bar beach thrown across the mouth of a channel between two portions of the lake, so that after passing over it, we begin to descend over another succession of beaches. These present the

same continuity as on the side first approached and our levels showed, that the rolling profile of beach ridges crowded together, continued from the crest at 168.2 feet to 140.8 feet. In this succession there is one prominent beach larger than the rest which has an altitude of 161.4 feet (XIV). Farther along the trail there is a distinct nearly flat terrace at the base of an escarpment of Keweenian rocks, of which two determinations of altitude at points ¼ mile apart, are 115.9 feet and 116 feet (X). Further along the face of the scarp a small terrace was found with an elevation of 127.4 feet (XI). The trail then passes over a remarkable sandy plain which appears to have been once shallow lake bottom. The plain was found to be about 132 feet above the lake but it is somewhat ridged in places and some sand dunes have been raised above its general surface.

Series 36.—Nipigon.—At some of the higher stages of lake Superior, lake Nipigon and the great lake into which it now drains by a succession of rapids must have had a common level. The present valley connecting the two bodies of water was always narrow and bounded by precipitate hills of rock, in which, however, there may have been notches affording other outlets than the present one. The channel was particularly narrow just where it would have emerged upon the open lake, being from ¼ to ½ mile wide according to the stage of the water. At one of these higher stages (which one is not definitely known but it was certainly over 200 feet higher than the present) a bar was thrown across the mouth of the channel partially or wholly shutting off the basin of lake Helen from that of lake Superior. This bar formed an immense beach which has been cut through by the Canadian Pacific railway just west of the bridge over the Nipigon river and is used as a gravel-pit so that its structure is well revealed. This great gravel beach is unfortunately covered by a dense jungle which renders its investigation extremely difficult. An attempt was made to ascertain its form and carry a line of levels to its crest. But it was soon realized that it was far from simple in its character and that no safe conclusions could be reached without giving the inquiry much more time than was at our disposal. An apparent crest was reached at an altitude of 198.3 feet, but the impression was obtained that probably the bar had been developed at successive stages of the water on the same general lines, and that the figures obtained afforded no reliable information as to any particular long-continued stage of the lake. But while the strand or strands to which the beach itself corresponds was not definitely ascertained, the slopes of the embankment afforded an excellent opportunity

for the registration of lower stages of the water. Upon its slopes there are several very distinct wave or current-cut terraces. Some of these face the open lake and record unequivocally a stage of its waters; others face the channel of the Nipigon river and are due rather to current scouring and therefore strictly of the nature of stream terraces; but being in immediate vicinity of the lake with no drop in surface of the water in the short distance which intervened, they represent also stages of the lake, the figures being a little smaller than the corresponding wave-cut terraces would give.

The highest of these flanking terraces is a broad forest covered plain which in the vicinity of the beach embankment, but not at the rear of the terrace, has an elevation of 131.7 feet (XII). The great breadth of this terrace, its flatness, and the fine sandy material of which it is chiefly composed, indicate that it is not a common shore wave cut or wave built terrace. It is a plain of deposition probably of the character of a delta, and yet it probably represents very closely a level of the lake. A few hundred yards behind Nipigon railway station the front of this broad terrace drops abruptly in the form of a sea-cliff at the base of which a sharp but narrow wave-cut terrace having an elevation of 89.8 feet (VIII). This terrace is traceable around the face of the great bar-beach to the vicinity of the Nipigon bridge. Another determination of its elevation obtained at this place gave the figures 89.9 feet. This narrow terrace in turn drops in a low sea-cliff to the terrace flat on which the railway depot stands and over which the track is laid. At its rear it has an elevation of 82.2 feet (VII).

Crossing the railway track and descending the wagon road to the Hudson Bay Co's. port, we cross three cut terraces having respectively the elevations 61.3 feet (VI), 28.4 feet (IV), and 13 feet (II). In addition to these there is a well marked terrace cut out of the slope of the great bar-beach on the lake Helen side of the railway bridge. This has an elevation of 53.3 feet (V).

Series 37—Mazokamah—About half a mile southeast of the mouth of the Mazokamah a high bluff of the Archæan juts out into the lake. On the streamward flank of this bluff there has been revealed by a recent forest fire, a series of remarkably sharp, step-like terraces overlooking Nipigon bay. The terraces, like so many others on this coast, are not cut into the rock, but into an earlier-formed embankment which lies imposed upon the rocky slopes. At the summit of the embankment is a great shingle beach bar at an elevation of 360.6 feet (XXIV) with a lagoon hollow behind it. The origin of this primary embankment is suggested by its proximity to the canon from which Mazokamah river

issues. It seems originally to have been an immense embankment which accumulated at the highest stage of the lake registered by the bar referred to. The conditions of coastal topography at this high stage of the water favored such a local accumulation. The stream supplied the boulders, shingle and gravel. The storms distributed them now on this side of the river's discharge and now on that. The portion which was cast to the eastward could not easily recross the mouth of the cañon. Its tendency to move as shore drift far from the point of discharge was effectually checked by the deep water off the jutting shoulder of the bluff. It was, therefore, confined within an open-mouthed bay of smaller extent, and as it accumulated, mantled the rocky slope down into hundreds of feet of water. It is out of this embankment that various later stages of the lake have wrought successive terraces, and at the same time added to its lower slopes. The terraces are generally uniform in character, the widest being about 120 feet and the narrowest about 25 feet, and all are equally sharp. The sea-cliff which rises from the rear of each terrace and extends to the brink of the next higher in the series is, with one exception, of the same character in all cases, and is a straight slope having a declivity somewhat less apparently than the ordinary angle of repose of such material, being probably about 24 degrees. The exception is the cliff between (XVI) 193.1 feet and (XVII) 214.5 feet, which is a rather uneven slope with a much gentler declivity The terraces have thus

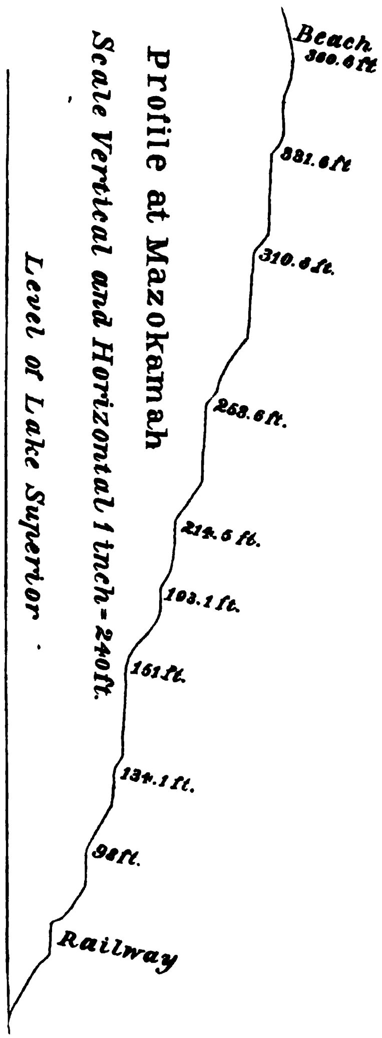


Fig. 11.

the character of the wave-cut type, but while this is their essential character it is very probable that at each stage of

the water the Mazokamah river continued to add fresh supplies to the shore drift, so that they are in part also of the character of Gilbert's "cut and build" terrace. The new accessions at each stage being of the same character of material as the embankment in which the cut was being made, it is difficult to distinguish between the cut shelf and its added extension. The vertical distribution of the terrace at this locality is shown in the accompanying diagram. Fig. 11.

Series 38.—Simpson Island.—The terraces of the north side of Simpson island are like those at Mazokamah of the wave-cut type. They have about the same lakeward slope and have similar but steeper cliffs rising from their rears. They present a decided contrast, however, to those on the opposite side of the bay at Mazokamah in the paucity of loose material which they exhibit. The terraces being formed on the side of an island there was no contribution of stream and gravel and the shore drift arising from the waste of cliffs was small in amount. The terraces are essentially cut out of the rock of the island and the vigor with which the cutting proceeded is shown in the steep and in some cases nearly vertical declivity of the sea-cliffs behind them. The rock is a sandstone, rather friable in places, with a distinct bedding and southerly dip at low angles. It is protected above by a heavy trap cap. These characters have favored the cutting of the terraces and the cliffs remain much as the shore action left them, having shed but a small amount of talus since the cutting ceased. The fact that the strata dip south while the cliffs face the north precludes the possibility of an unmodified shelf of rock having been mistaken for a

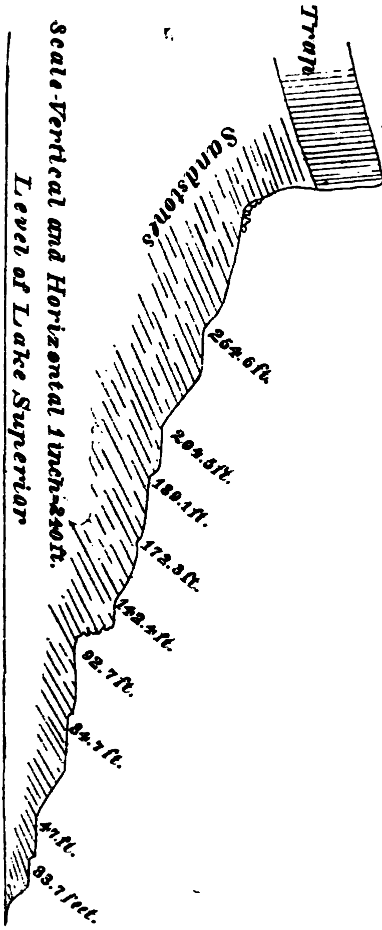


Fig. 12. Profile of north side of Simpson Island.

terrace. The ground has been well burnt of its timber and the terrace slopes are well defined. There is some sandstone and shale-shingle and trap pebbles of local derivation, but these are more abundant on the lower than on the upper terraces so far as the vegetation will permit of observation. The width of the terraces varies from about 25 to 300 feet. The highest terrrace is 254.6 feet above the lake, and at its rear rises a precipice upon which the higher levels have not been registered, or if so, such registration has been obliterated by the undermining action of the Grand Portage stage (XX) of the lake.

Series 39.—Winston's—At Winston's siding half way between Rossport and Schreiber is a heavy but quite local accumulation of coarse delta material which has been opened as a gravel pit. The material has been supplied by a small stream which has probably traversed a moraine, as the material is very heterogeneous. The embankment appears to be essentially of the character of delta, spreading out fan-shaped from the mouth of a little canon, but much modified by wave action. Its upper surface in the vicinity of the pit was found to have an elevation of 210 feet (XVII?) The surface is here gently sloping and the maximum hight was not obtained. The general nature of the embankment was not realized when first examined and its altitude measured, and it was only later when viewed at a distance from the lake that its delta character became apparent.

Series 40.—Schreiber—The railway shops at Schreiber, a divisional point of the Canadian Pacific railway, and the small town which is growing up around them, occupy a perfectly level piece of land less than a square mile in extent in a region where such level tracts are exceedingly "few and far between." This flat is rudely triangular in shape, one side facing lake Superior, the shore of which is two miles distant. On the other two sides it is bounded by bare or scantily wooded rocky hills which rise irregularly to elevations of a few hundred feet within sight of the railway station. On the northwest side of the flat where it abuts upon the rocky slopes, a small rapid stream from the north has cut a deep sharp gorge down to bedrock showing a thickness of detritus which varies according to the uneven character of the rocky floor, but which probably averages over 100 feet. The rocky ridges which bound the two sides of the flat continue lakeward as bold promontories so that the flat occupies an embayment in the hills. The lakeward boundary of the flat is a beautifully defined beach bar which extends across the embayment from ridge to ridge save where it has been cut through by the stream. The ground has

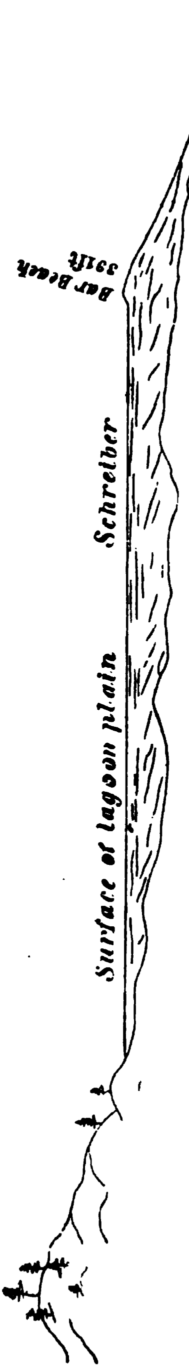


Fig. 13.

Profile at Schreiber Scale, Vertical and Horizontal, 1in.=500ft.

been cleared of the heavy jungle by fire and the characters of the beach bar are not disguised by the thin veil of new growth. The crest of this bar has an altitude of 391 feet above the lake, and on its front it descends rapidly lakeward till it reaches the uneven rocky slope upon which it is imposed. The flat behind it is a filled-in lagoon having a uniform elevation of about three or four feet below the crest of the beach bar. The history of the development of the topographical features thus described cannot be stated in detail from the brief study given to it, but broadly it appears to be as follows: At the higher stages of the lake the stream coming from the hills at the apex of the old embayment dumped its sediment and gravel into the then bay. All but the gravel[1] of the sediment was retained within the bay owing to the deep water off its limiting promontories, and formed a heavy embankment at the bottom of the bay. As this embankment extended lakeward the point of discharge of the stream was apparently carried sufficiently far lakeward to come within the influence of the waves and currents of westerly and southwesterly storms, so that a spit was developed running easterly, which eventually spanned the bay and became a bar. The choking of the first channel of the stream and the filling in to a uniform level of the inclosed lagoon would naturally follow.

Other lower beaches or terraces may possibly be found between this beach bar and the present shore line, but on the trail followed by the writer none were clearly recognized, the country being rough and difficult of inspection.

Series 41.—Terrace bay.—Terrace bay has long been noted for its terraces and their character, as ancient strands of lake Superior were recognized as early as 1847.*

The embayment occupied by Terrace bay is rudely horseshoe-shaped and the hills rise steeply above the bay in a succession of great terrace steps, like a magnificent amphitheatre. These terraces are ideal in their perfection of form, free of timber for the most part, and as sharp in their profile as if they had been constructed of masonry. The embayment seems to have been originally occupied by an immense embankment which spanned the valley, the abundance of the material being due doubtless to the proximity of the early representative of the Black river, which now enters lake Superior a little to the east of Terrace bay. The top of this embankment is a broad well-rounded beach, the crest of which is 392.2 feet (XXV) above the lake. It evidently was a bar beach which separated a deep lagoon from the open lake. It is on the front of this embankment that the terraces have been constructed.

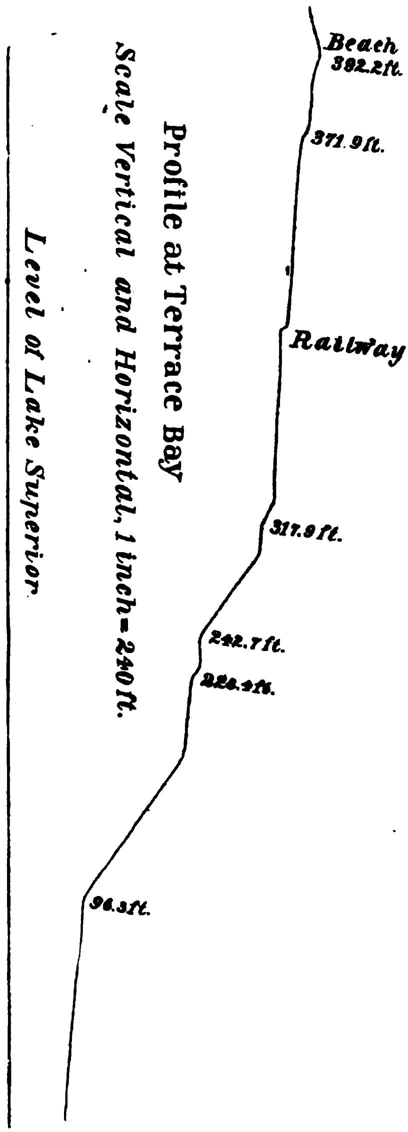


Fig. 14.

The material of the embankment is unconsolidated gravel andpebbles, and the cliffs at the rear of each terrace have the angle of repose of such material, viz., uniformly 34° by measurement. The width of the terrace varies from 1,000 feet to 50 feet. The series

*Logan—Report of Progress, Geological Survey of Canada.

is so simple in its general character that no farther description is necessary. A profile plotted from measurements is given, which it is hoped, will afford some idea of the distinctness of the terraces. The elevations obtained for the rear part of the different terraces are as follows: 96.3 feet (IX), 228.4 feet (XVIII), 242.7 feet (XIX), 317.9 feet (XXII), 371.5 feet (XXIV). The impression which an inspection of the series gives is that, having been developed at different and distinct stages of the water, the subsidence of the lake must have been by great leaps from the level of one terrace to that of the next below. This notion is, however, at once corrected, when it is remembered that the development of one terrace may involve the destruction of many or all of the earlier formed terraces or benches. The number of the terraces is, therefore, no indication whatever of the number of distinct and long-continued stages of the lake. These terraces are essentially wave-cut terraces, but as the supply of material for construction doubtless continued at all stages, to some extent at least, they may in part be current-built terraces. And as the material from the cliffs in process of recession would be the same as the shore drift supplied by neighboring streams, there would be no observable difference between the portion of the terrace which is cut and that which is added to it, and there would be no break in the profile.

Series 42.—Jackfish Bay.—On the east side of Jackfish bay, just south of Jackfish station on the Canadian Pacific railway, there is an embayment in the hills which is now spanned by a railway embankment, which, at its highest part, is about 85 feet above the lake. The upper part of this embayment was, at the highest stage of the lake of which there is here a record, the seat of the accumulation of an immense embankment. The surface of the embankment is apparently flat and no rise could be detected with the spirit level for a distance of an eighth of a mile. It passes under the timber and its full extent was not determined. It appears to be a delta plain of a drainage system which found other outlets as the waters of the lake fell to lower stages. The elevation of this delta plain was found to be 418.3 feet. (XXVI) On the front steep slope of the delta there have been carved two very distinct terraces, both with well-defined steeply sloping sea-cliffs remarkably uniform and intact. The first of these in descending order is about 100 feet wide and at the base of its sea-cliff has an altitude of 391.3 feet (XXV). The second terrace is smaller but no less distinct. Its elevation is 367.2 feet (XXIV). Below the front of this terrace the profile of the surface changes from the step-like character given to it by the terraces to a gentle slope ex-

tending to the present shore about a mile distant. On this slope, on which the underlying rock may in places be seen protruding, a great many shingle and gravel beaches have been thrown up at different stages of the lake; and we have here perhaps the fullest representation of the ancient strand lines of the lake that is to be found anywhere on this coast.

The first five of these beaches are distinct from one another being well spaced both vertically and horizontally. Their individuality is no less marked than their general perfection of form, size, and continuity. They are concave lakeward and usually have a distinct depression behind them. The country has been burnt and they are easy of access for purposes of examination.

The figures obtained by our leveling for the crests of these five beaches is as follows: 317.2 feet (XXII), 259.2 feet (XX), 237.9 feet (XIX), 228.5 feet (XVIII), and 175.6 feet (XV). About 6 feet above the last (XV) there is a beach-like ridge which may also be indicative of a distinct stage of the water, but was thought to be a feature of practically the same shore as that at which beach XV was developed. On the lower slope of beach XV there is a narrow terrace which appears to be cut into the higher embankment at an elevation of 157.9 feet (XIII). The ground is somewhat obscure at this place and the fact that it was really a cut terrace and not the incipient form of a wave-built terrace was not clearly established. Continuing down the slope there are well defined and distinctly spaced beaches at elevations for which we obtained the following figures, viz: 135.9 feet (XII.), 127.7 feet (XI an exceptionally large beach), and 119.5 feet (X).

These are followed by a continuous succession of rolling beaches, the highest of which has an elevation of 110.1 feet and the lowest 84.9 feet; of this succession the most prominent are the last mentioned and one at 102.9 feet which are placed in the table as strand lines (VII) and (IX); between these two for a distance of 1200 yards one beach follows another closely. An inspection of the ground leaves little doubt in the mind of the observer but that there was a gradual and comparatively regular recession of the waters of the lake from the stage corresponding to the 110.1 foot beach to that at which the 84.9 foot beach was formed. On the lakeward side of the railway embankment we find another rolling succession of beaches, the figures for the crests of which are as follows: 57.1 feet (VI), 53.8 feet, 51 feet and 46.2 feet (V). These follow one another closely and again indicate a lowering of the water by easy stages. Separated from these by an interval are two lower beaches quite distinct from each other. The first is an

embankment of great size at 33.5 feet (IV); and the second is less prominent and has an elevation of 19.2 feet (III). The lowest record is that of a small wave-built terrace 9.8 feet high, the product of the waves of the present stage of the lake and which is an abandoned terrace only as regards its rear portion. Its front is still growing. It is a significant fact that the only horrizontal wave-built terrace in this very full record of shore lines is that of the present strand and suggests that the present stage has been perhaps the most enduring of the many through which the lake has passed. Where conditions for the development of shingle and gravel beaches have been so favorable, it is remarkable that no single stage of the lake should have lasted long enough for the construction of the characteristically rigid wave-built terraces which are seen at some places along the present shore.

Series 43—Three miles east of Jackfish.—Just around the rocky point which defines the limit of Jackfish bay and about three miles or less from Jackfish station may be seen another fine series of strand lines which present a strong contrast to those last described. We have seen that in series 42 the conditions of the embayment favored the growth of beaches and that with the exception of two terraces near the top of the series there are practically no well defined wave-cut terraces. In series 43 just around a jutting ridge of rock which separates the two embayments, we have a fairly full series of strand lines in which there is not a single beach, the whole series being composed of terraces. The embankment in which they are cut is an extensive one in which a large gravel pit has been opened for the railway. Its upper surface is quite flat, so far as could be observed and its entire extent was not investigated. It appears in places to abut sharply against projecting portions of the rocky ridge. It appears to be analogous to the embankment at the head of the Jackfish embayment of series 42. Its elevation is 212.9 feet (XVII). The front of this terrace is limited by the sea-cliff of a lower terrace which has an elevation of 174.5 feet (XV). This terrace is very narrow owing to the recession of the sea-cliff of the next lower terrace which is that upon which the railway track lies. This has a maximum elevation of 111 feet, but the precise rear of the terrace is not susceptible of exact determination, and this figure (111 feet) was considered in the field several feet too high for what is probably the true rear of the terrace. Below this are four well defined cut terraces having the following altitudes, viz: 59.2 feet (VI), 47.3 feet (V), 40 feet (IV) and 16 feet (III). Below this is a great beach which appears

to be yet within reach of exceptional storms although its crest is 13.3 feet high. By an error it appears in the table as strand line II.

Series 44.—Dog River.—To the east of the Dog river we have a set of conditions somewhat analogous to those at Terrace bay. At a very early date Dog river was a source of supply for a great mass of shore drift. The prevailing storms have thrown it all to the east side of the river, where at a high level of the lake it accumulated in a great embankment. On the summit of this embankment at a point about three miles east of the mouth of Dog river, a beach was thrown up which separated a shallow lagoon from the open lake. Below this beach on the front of the embankment there have been cut numerous terraces which are well preserved and perfect in form. The crest of the summit beach is 323.4 feet (XXIII). The following elevations were obtained for the rear part of the various terraces in descending order: 314.7 feet (XXII), 255.4 feet (XX), 215.6 feet (XVII), 100.7 feet (IX), 39.7 feet (IV), 16.5 feet (III). A very interesting feature of this series is that the actual process of their development may be observed in progress at the present shore. The cliffs are there actively receding and have a declivity which is the angle of repose of the gravel and sand of which the primary embankment is composed. The recession has gone so far that for a considerable distance the 16.5 foot terrace has been entirely obliterated save at points where it is protected from undermining by a projecting basement of hard rock. A broad sub-aqueous terrace of very gentle slope is being formed and the waves which traverse this shallow shelf being feeble at the shore line, the rear of the terrace where it abuts upon its sea cliff is precisely the level of the lake.

Series 45.—Sand River.—On the south side of the Sand river about a quarter of a mile from its mouth are two terraces the lower of which is very distinct while the upper is somewhat indefinite and hard to recognize on account of large numbers of huge boulders which cumber it. The terraces are composed mostly of boulders and large pebbles brought down by the stream. They flank the rocky walls of the canon in which the stream flows, but their position is clearly conditioned by a former level of the lake, the stream having cut through them as the lake subsided. The levels obtained for these terraces are 75.2 feet (VII) and 118 feet (X).

Series 46.—Montreal River—The Montreal river in its lower stretch is a torrent rushing through a very narrow, high-walled canon whose form is due to structural planes in the granite of the country. This torrent has brought down to the lake a large

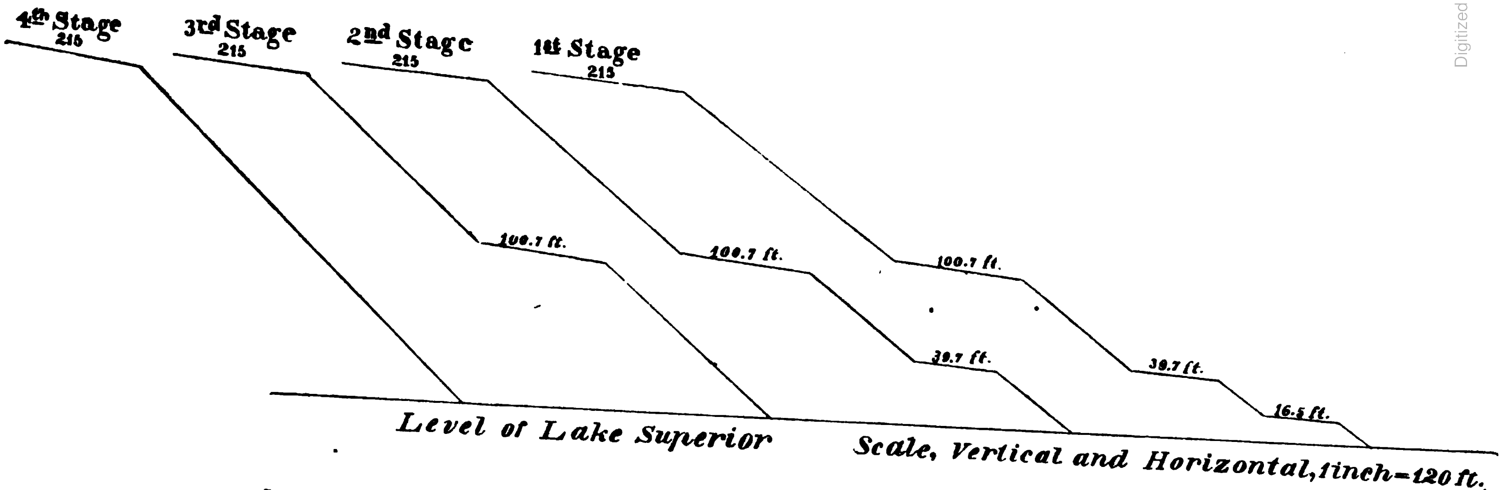


Diagram illustrating obliteration of Terraces east of Dog River

1st Stage shows four actual Terraces.
In the 2nd stage the sea cliff of the present shore has receded till it coincides with the sea cliff of the 16.5 ft. terrace.
In the 3rd stage the same sea cliff has receded till it coincides with that of the 39.7 ft. terrace. In the 4th stage 3 of the four terraces have been obliterated.

Fig. 15.

amount of very coarse material which has been dumped at the mouth of the canon and spread out in the form of a delta. The surface material of the delta consists chiefly of large boulders and angular blocks whose average diameter is perhaps three feet at the mouth of the canon, with masses of less size down to cobble stones farther lakeward. The finer gravel has been carried to the outer edge of the delta and there thrown up into a magnificent beach through which the stream maintains a narrow passage to the lake. This fine bar has its counterpart for an older phase of the stream at an elevation of 211.3 feet (XVII) less than half a mile up the canon and above the edge of its more precipitous part. The bar has the form of a great beach extending across the valley and although covered with timber is easily recognized by its form and by the material of which it is built. This bar beach forms the crest of a great embankment probably much the same in character as that accumulating at the mouth of the present stream. On the front slope of this embankment there have been developed four sharply marked terraces. The upper two of these have elevations of 134.8 feet (XII) and 78.7 feet (VII), respectively, the first being over 100 feet wide and the second not more than 25 feet. Both appear to be essentially wave-cut terraces and have sea-cliffs as steep as the material of which the primary embankment is composed will lie. The lower two terraces have elevations of 61.9 feet (VI) and 45.2 feet (V) and are the surfaces of former deltas which have been cut through by the lowering of the base level. Their proximity to the open lake and their position below the precipitous narrow part of the canon make it clear that their elevation is approximately that of the lake at the stage at which their rear part was built. They have no true sea-cliffs, and they lie below the level of rocky surface upon which the higher embankment with its secondary terraces rests.

Series 47.—Mamainse.—At the deserted mining village of Mamainse three of the ancient shore lines of the lake may be recognized by the usual characteristic features. The lowest of these is a gravel and shingle beach which skirts the back of the old stamp mill. Its crest, where crossed by our levels, is 122.1 feet (XI). The second is a distinct terrace which at its rear was found to be 156.8 feet (XIII). The third is also a terrace, but a somewhat extensive one, the rear of which was not observed. It is an apparently flat gravel plain, thickly timbered, the surface of which, near its brink, is 191 feet above the lake (XVI).

Series 48.—Sault Ste. Marie.—The last of our series of the ancient strand lines of lake Superior is in the vicinity of the present outlet of the lake, and is interesting for its geographical position between lakes Superior and Huron; for the high levels at which the strand lines are observable and for their well-preserved and unequivocal character. The terracing of the hills on the north side of the St. Mary's river is a conspicuous figure of the topography and may be readily examined at many points. The town of Sault Ste. Marie, in Ontario, is, like Port Arthur, built upon terraces. Of those within the town, two are very prominent, and there are suggestions of others. Only the lower of these two terraces has its sea-cliff (possibly stream cliff) within the town limits. The base of the cliff is just north of the line of the Canadian Pacific railway track, and on Pim street, where our levels were run, the rear of the terrace was found to be 49 feet above lake Superior (V). The cliff rises steeply and is composed chiefly of clayey material. The second terrace which extends back from the upper edge of the cliff, is a broad plain, at least a mile in width, and does not appear to have a well-defined cliff at its rear, but to have a sinuous abutment upon a series of low tumultuous hills composed of morainic drift. The altitude of this broad terrace at its rear was not precisely determined although our levels crossed it, but it is probably about 150 feet. These two terraces are distinct from the remaining members of the series which are grouped together farther back on the front part of the hills. They are probably best seen on the Tarentorus road, about four miles from the town of Sault Ste. Marie. Here an immense embankment has been accumulated along the front of the hills in the embayment now occupied by the Root river, which has since cut a deep canon through it. This embankment culminates in a great gravel and shingle beach, the crest of which is 413.9 feet above the lake (XXVI). Immediately below this there is a rolling succession of three benches for which the following elevations were obtained: 403.3 feet, 404.8 feet, and 400.4 feet, the succession indicating a stage of the water somewhat lower than XXVI at which there was a tendency to form a wave-built terrace with a gradually subsiding lake. A few hundred feet down the road we come upon a good terrace, the rear of which is 365.3 feet above the lake (XXIV). On the front part of the terrace is a distinct but low beach, two feet lower than the rear of the terrace. The road then drops to the level of another terrace which is several hundred yards wide and which has an altitude at its rear, where it encircles an island-like mass of rock that projects through it, of 311.2 feet

(XXII). The front of this terrace is the front of the primary embankment of shore drift and there are cut into its steep slope four wave-cut terraces ranging from ten to fifty feet in width, all well defined. The elevations obtained for these, in descending order are, 223.9 feet, (XVIII), 207.6 feet (XVII), 174.4 feet (XV), and 150 feet (XIII).

DISCUSSION OF RESULTS.

The facts set forth in the preceding pages, regarding the hypsometric and geographic distribution of the observed abandoned strands on the coast of lake Superior, suggest many interesting problems which cannot be here entered upon. The information which has been won is but a contribution to an inquiry into a very important chapter in the recent physiographic development of North America. The full inquiry will require the labor of many investigators through many years before entirely satisfactory and invulnerable conclusions are attained. A few preliminary inferences and suggestions, arising from a consideration of the data which has been presented, may here, however, be discussed briefly.

Up to the present point the abandoned strands with which we are concerned in this inquiry have been discussed as topographic features of the *coast* of lake Superior, and they have been alluded to as having been developed at the higher stages of that lake. But a little reflection will make it clear that all but the very lowest of these strands represent stages of a sheet of water which was very different in its general physiography from the present lake Superior. It was many times more extensive than lake Superior, and covered the entire region of the great lakes Huron and Michigan with several hundred feet of water. The extent of this vast lake was probably at least twice as great as the combined areas of the present lakes Superior, Michigan and Huron, or about 150,000 square miles; and these lakes are but the remnants of its waters gathered together in the subordinate depressions of the once greater basin. The Algonquin beach which skirts the coast of lake Huron marks but an episode in the later stages of subsidence of this remarkable sheet of fresh water. For such a lake it would be manifestly incongruous to retain the name lake Superior, and confusion would constantly arise by such a usuage. It is, in fact, scarcely possible to discuss the problems presented without some distinctive name for the immense lake which played so important a rôle in the post-glacial physiography of the continent, and of

which the present great lakes are but residual parts. The necessity for such a convenient designation has been anticipated by Spencer, who has suggested for this great lake the name LAKE WARREN.*

By lake Warren, then, will be understood the great sheet of water along whose successive shores were developed the terraces and beaches now apparent on the north coast of lake Superior; and the name will be applicable to this lake from its highest stages down to that stage when its waters became definitely segregated into the different subordinate depressions, and assumed the characters of the present great lakes. The different shore lines of lake Warren may, of course, receive special designations without in any way interfering with the name of the lake itself.

A glance at the table shows that in different parts of the coast of lake Superior the number of observable strand lines varies from one to nineteen; while along very considerable portions of the coast none can be detected. This great discrepancy in the records of the different distinct stages at which the waters of the lake Warren have stood is to be accounted for in different ways. Of course a very large proportion of the discrepancy is only apparent, and is due to the fact that the coast is a timbered country. Were the coastal slope stripped of its timber many of the local series of strand lines would have a much fuller representation than is shown in the table. And in this respect forest fires are coming rapidly to the assistance of the inquiring geologist. If fire continues its destructive work in the future as vigorously as in the past few decades, the record of ancient beaches and terraces will in many places be much fuller than is here given. But apart from gaps in the series due to obscuration of the topography by timber, there are many localities where the topography is well exposed, and all the beaches and terraces present may be accurately determined; and on comparing these with one another very serious differences are at once apparent, even when the localities are not widely separated. These may be due to one or another of two causes. (1) The coastal slope is not equally susceptible of receiving the registration of shore lines at different levels. One portion of the slope may be admirably adapted to the formation of sea-cliffs and embankments, while another portion either above or below may not lend itself to the development of such features. This difference in susceptibility of receiving shore line impressions is due partly to the varying character of the rocks and partly to the general steepness of the coastal slope. (2) A second cause of the lack of con-

*Trans. Roy. Soc. Can., Sec. IV, 1889, p. 122.

cordance between the different series of shore features is that many of them, particularly those which take the form of terraces in pre-existing embankments, have been obliterated by wave action operating at lower levels than that at which they were formed, by the process described as now in operation near Dog river.

There is, however, still another important possibility to be considered. There may have been differential movements within the limits of the present lake Superior basin when its outlet was relatively higher than at present. There are two general cases under such a supposition: (1) the differential movement may have been of such a character that a portion of the coast did not change its altitude relatively to the outlet, while another portion did so change; or (2) the entire coast, within the limits named, may have changed its altitude relatively to the outlet, or become inclined. In the first case one shore line in one part of the coast would correspond to more than one shore line in another part, *i. e.*, there would not be in all parts of the coast the same number of abandoned strand lines even if the record were quite complete. But the supposition is a violent one, involving post-glacial faulting or flexure of which there is no evidence whatever. In the second case there would be an equal number of strand lines in all parts of the coast (supposing none were re-submerged) but all would converge upon the outlet if projected on a vertical plane.

In both cases the vertical interval between the same pairs of strand lines in all different parts of the coast would not be constant Moreover, it would be by the merest chance that in the second case the same figures would be obtained for the vertical interval between strand lines in different parts of the coast. If it can be shown that, notwithstanding the actual discrepancies in the different local series, there is a prevailing constancy of interval between strand lines in different localities, we shall not be warranted in assuming that the discrepancies apparent in the table are due to local move mentsat a time when the basin was fuller than now. To be convinced that there is a prevailing constancy of interval one has only to study the table of elevations, bearing in mind the fact, that the elevations given of the ancient shore features of lake Warren may differ a varying number of feet (ordinarily up to ten feet) from the actual water level at which they were formed. In the table will be found many striking coincidences of vertical interval; and the nature of the problem is such, that positive evidence of this character is important, while negative evidence is practically valueless, owing to the fact many conditions may cause apparent discrepancies, while only one set of conditions would favor a con-

stancy of vertical interval between the abandoned strands, viz., *a uniform subsidence of the water along the entire extent of the coast.* Not only is there a prevailing constancy of interval between the abandoned strands, suggesting the correlation implied in the table, but when we compare the intervals between the strands of the various local series and the present level of the lake there is a far more imposing array of coincidences. This becomes apparent in the following table, in the consideration of which it must be again remembered that, if the same features were to be subjected to the same kind of measurement, there would be a maximum discrepancy for the present level of the lake of 15 feet. In addition to this there are possible errors of observation and instrumental errors to be taken into account; so that the maximum discrepancies in the following table are very moderate in extent.

TABLE

Showing the extent of coincidence of the vertical intervals between the level of lake Superior and some of the abandoned strands of lake Warren at various well distributed localities on the coast.

Number of localities.	Maximum and minimum values of the interval in feet.	Maximum discrepancy in feet.
7	17.6- 12.1	5.5
11	21.7- 16.0	5.7
17	40 0- 27.2	12.8
18	53.3- 43.0	10.3
10	61.9- 55.9	6.0
18	86.8- 74.4	12.2
5	92.7- 89.2	3.5
12	106.3- 97.0	9.3
9	119.5-113.5	6.0
9	129.2-122.0	7.2
10	142.4-134.1	8.3
6	157.9-148.8	9.1
4	162.6-160.5	2.1
8	175.6-170.0	5.6
3	193.1-189.1	4.0
7	215.6-204.5	11.1
7	231 8-221.8	10.0
2	142.7-237.9	4.8
7	261.2-253 6	7.6
3	288.4-278.9	9.5
7	313.9-310.6	3.3
3	331.6-323.4	8.2
4	371.5-360.6	10.9
4	392 3-391.0	1.3
2	418.3-413.9	3.4
2	439.7-436.2	3.5
3	475 9-473.0	2.9
2	509.5-509.5	0.0
2	534.8-534.0	0.8

This remarkable coincidence of vertical interval could not be a matter of accident, and it seems to the writer to warrant the correlation of the abandoned strands of the lake as expressed in the table. But if this be granted it also demonstrates another im-

portant fact: viz., The lack of local deformation in the strand lines since their abandonment by the subsiding waters of the lake. For it is clear, that if the strands are to be correlated as indicated in the table, they are as perfectly horizontal as when they were functional shores. And in this statement we have a satisfactory, even if unexpected, answer to the question proposed at the outset of the investigation.

It follows from this conclusion, that every distinct altitude occupied anywhere on the coast by a strand line represents a stage of lake Warren. In other words, the total number of observed strands marks the minimum number of distinct stages. There are recorded in the table 33 strands having distinct altitudes. With reference to one of these (XXVIII) there is some doubt as to its representing a stage distinct from one recorded at a lower level. Thus there have been in the history of the recession of the lake at least 32 definite stages. The maximum number recognized in any one locality is 19, so that the minimum defect in the record in the most favored locality is 13, i. e. in the most complete series only 60 per cent. of the minimum complement of shore lines is represented.

So far as can be inferred from a consideration of the observed strand lines, the subsidence of the lake may have been effected by a gradual lowering of the waters, with a definite halt at each of the stages represented by a strand line in the topography of the coast; or the waters may have dropped rapidly from one stage to another. The latter assumption for so large a sheet of water involves so much violence that it is naturally repugnant to the geological mind. The only probable condition which would give rise to a rapid drop in the water of the lake would be the rupture of an ice dam. But, as will be urged in the sequel, ice barriers appear to be ruled out of the problem. Conditions favoring the rapid trenching of soft material, such as morainic dèbris, producing effects similar to the rapid lowering of lake Bonneville, are possible; but in the utter absence of evidence of such action this possibility can scarcely be entertained at present. It seems probable, then, that the lowering of the water has been gradual. But while this is so it does not imply that the subsidence was uniformly gradual; the occurrence of successions of beaches following one another closely on certain of the lower portions of the coastal slope (as has been indicated in earlier pages of this paper) seems to mark a much more gradual subsidence within certain limits of elevation than that which usually obtained. On the other hand, the wide vertical gaps between the strand lines in the higher parts of the coast may in-

dicate a more rapid lowering of the water, or at least less frequent stoppages of the process of subsidence. But owing to the imperfection of the record the evidence is at best only suggestive on this point.

There can be little question but that every one of the many stages of lake Warren had its level determined by a definite outlet, just as the level of lake Superior is conditioned by the overflow at Sault Ste. Marie. The existence of post-glacial beaches and terraces at high levels in the vicinity of Sault Ste. Marie, demonstrates clearly that no ice barrier, spanning the interval between the high ground on the north side of the lake and that on the south side, can be invoked to explain the high level strand lines of the north coast as those of a body of water dammed back by a glacier lobe, and corresponding in geographical extent approximately with the present lake Superior. It was a sheet of water of much vaster proportions; and for such it is entirely reasonable to suppose that epeirogenic movements may have been in progress in one portion of its area and not in others; or that a movement of uniform elevation or depression in one part may have proceeded contemporaneously with local warping in another. Further, since the supposition of an ice barrier at Sault Ste. Marie is out of the question, and since there is no known single gorge of post-glacial age which, by being progressively trenched, would, without crustal warping, account for the lowering of the waters through a range of 600 feet, we seem, so far as our present knowledge serves us, to be forced to assume crustal deformation as the primary means of the lowering of the outlet of the lake. A consideration of the abandoned strand lines of the north coast of lake Superior warrants the conclusion that whatever deformation may have been in progress, the region examined was not locally warped, although it may have been uniformly uplifted or depressed. Thus it seems probable that local warping of the crust, in some region far removed from lake Superior, is accountable for the lowering of the land barrier which held back the waters of lake Warren. The region in which evidence of such changes should be looked for lies to the south and southeast of lakes Michigan and Huron; and the movements which here concern us are probably closely related to those revealed in the warping of the Iroquois and Algonquin shore lines, as described by Gilbert and Spencer. These warpings, however, must represent a late movement in the general process; since the scoring of the Algonquin beach of Spencer is probably only a recent episode in the subsidence of the great sheet of water which embraced all three of the upper lakes.

The general epeirogenic result of the movements which lowered the southern and southeastern barrier of the basin of lake Warren, and caused the registration of the great succession of strand lines now observable on the north coast of lake Superior, seems to have been an absolute and uniform elevation of a large portion of central Canada, including the region about lake Superior, of several hundred feet, and a relative, and probably also an absolute, depression of the region south of the present lakes, embracing the states of Ohio and Indiana. For on the north side of the divide between lake Superior and Hudson's bay, at a distance from lake Superior of from 150 to 200 miles, post-glacial marine deposits occur on Kenogami river at an elevation of 450 feet above the sea, extending thence continuously to the shore of James' bay; and similar post-glacial marine deposits occur on the Missinibi river at an elevation of 300 feet.* Since the occupancy by the sea of these e ions north of the divide and the high stages of lake Warren are both clearly post-glacial, we would seem to be warranted in correlating the two events; and also in further correlating the gradual subsidence of lake Warren with the emergence of the Hudson's bay slope from beneath the sea.

If the general supposition be true, that the draining of lake Warren was due to the relative lowering of a land barrier far southeast of the present lake Superior, it seems probable farther that the outlet of this vast sheet of water shifted from time to time in consequence of the continental warping. It would be quite reasonable, also, to suppose that if a southerly land barrier conditioned the high levels of lake Warren, the same barrier may have been high enough at first to determime a northerly drainage of the lake to Hudson's bay. The suggestion that such was the case is strengthened by the following interesting circumstance.

The hight-of-land portage south of Long lake, *i. e.*, the divide between the St. Lawrence system of drainage and that of Hudson's bay, is only about 15 miles distant from the shore of lake Superior. The elevation of this pass is 1,102 feet above the sea,† *i. e.*, it is 500 feet above the present level of lake Superior. The description of the pass by Bell leaves little doubt but that it is the abandoned bed of a large river. Now one of the most heavily marked of the abandoned strand lines of the north coast of lake Superior has a precise altitude of 509 feet. The coincidence is a remarkable one, and it is difficult to resist the conclusion that stage XXX of the lake was determined by the altitude of this pass, the drainage be-

*Bell, Geol. Survey of Canada, Report of Progress, 1871-72, p. 112, and 1875-76, p. 340.
†Upham, Bull. Geol. Soc. Am., Vol. 2, p 263.

ing northward. Mr. Upham, if the writer understands him, regards this pass as an outlet for the southerly drainage of a hypothetical lake, dammed back to the north by a wall of ice; but the writer can find no warrant for Mr. Upham's supposition. It is not improbable that the continental ice sheet was still extensive towards the east at the time that lake Warren stood at stage XXX; and it is possible that a lobe of its southern margin may have reached nearly as far south as Sault Ste. Marie. But it had certainly disappeared from the present coast of the northwestern part of the lake and probably had been sufficiently removed from the region northward to permit of the northerly drainage here suggested.

About 50 miles northeast of Michipicoten harbor is another pass, somewhat lower, at an altitude of 440 feet above lake Superior,* at thedivide south of Missinaibi lake. It is possible that this pass may have been blocked with the ice sheet when the Long lake outlet was open, or it may have been blocked with morainic débris which has been since trenched by stream action. If this pass ever served as an outlet of lake Warren it is doubtless to be correlated with stage XXVI which has so strongly marked a strand line at Sault Ste. Marie.

There are other possible outlets concerning which, for lack of information, it is impossible for the writer to speak definitely. It seems not improbable, for instance, that the valley of the St. Croix river served as an outlet for the overflow of some of the high stages of lake Warren, conveying its waters to the Mississippi. The bed of an old channel at the lowest point of the divide between Bois Brulé and St. Croix rivers is described by Upham, who gives the elevation as 468 feet above lake Superior.† This seems to correspond well with strand XXIX of lake Warren, which, at Duluth, has an elevation of about 475 feet. There are possibilities of another outlet to the same general drainage by way of the Illinois river. The Fort Wayne channel doubtless offered another outlet at a different attitude of the surface and a greater absolute elevation than it now has. The Nipissing depression may possibly have been available at some of the higher stages.

Prof. N. H. Winchell, also, has suggested that there is a former outlet by way of Whitefish valley through Little Bay de Noc.‡

*Upham, op. cit., p. 264.

†Op. cit. p. 258.

‡Am. Jour. Sci., Vol. II. 1871, p. 19.

VI.

DIATOMACEÆ

OF MINNESOTA INTER-GLACIAL PEAT.

BY BENJAMIN W. THOMAS, F. R. M. S.

WITH A LIST OF SPECIES AND SOME NOTES UPON THEM, BY PROF. HAMILTON L. SMITH, M. A., L. L. D. ALSO DIRECTIONS FOR THE PREPARATION AND MOUNTING OF DIATOMACEÆ. BY DR. CHRISTOPHER JOHNSTON AND PROF. H. L. SMITH.

Samples of inter-glacial peat from Blue Earth county, Minnesota, sent by Prof. N. H. Winchell, state geologist of Minnesota, were found to be well filled with the siliceous frustules of over 100 different species of fresh water "Diatomaceæ." The stratum of peat from which the specimens were taken was reported as being overlaid by some twenty-two feet of boulder clay, and as resting upon the same material, but I am not advised as to the extent or thickness of the peat in this interesting deposit. The clay both above and below the peat carried many boulders showing glacial striation and on microscopical examination yielded Foraminifera, Radiolaria, and other marine forms peculiar to Minnesota, and some other western boulder clays, but marine forms were not detected in the peat.

Diatomaceæ constitute a group of microscopic organisms of great interest to the student of natural history. They are a family of confervoid algæ of very peculiar character, and the living forms are found in great numbers in almost all waters that are exposed to the sun and air, forming a brown, or yellowish layer at the bottom of the water, adhering to submerged logs and rocks, or attached to the fronds of the larger algæ. Specimens which contain the living diatoms are of course the most valuable for the proper study of their life history, but the plants are so variable in character and habit that it is difficult to give directions that will in all cases give the

best results for collecting and preserving them. Collections should be made of plants growing entirely beneath the water, attached to rocks, piers, logs, etc., or to the larger algæ. The slimier the plants appear, if in water free from sand and mud, the richer will be the harvest, as the brown, or yellowish coating upon the algæ and other submerged objects is frequently but a mass of living Diatomaceæ and the moss-like carpeting upon submerged rocks, is often largely made up of beautiful specimens of the filamentous species.

The growing algae, carefully taken from their attachments, can be thoroughly dried, and each collection carefully placed in separate paper boxes, or wrapped in strong, clean paper, and plainly labeled, giving locality, date of collection, etc., or they may be kept moist in phials or small bottles, with a little creosote added to prevent mould, as recommended by Prof. Smith. When prepared either dry or moist as above suggested they can be carefully laid away for future examination, and the dried material can safely be sent to correspondents by mail or otherwise.

But as many of the most carefully collected and promising specimens prove to be of little or no value it is not only desirable but also a most interesting and profitable study to examine them while fresh from the water.

For this purpose with a pipette take a small quantity of sediment from one of the collecting bottles as soon as possible after its collection, and before creosote or other preservative has been added, put a drop from the pipette onto a microscope slide, place a cover glass over it and with a blotter absorb the surplus water. If the collection is of good material the microscope with a one-fourth inch objective will show an abundance of living diatoms, with their rich and beautifully colored endochrome. Some of the frustules will be connected by *stipes* to the larger algæ, some in *tubes*, others in long ribbon-like *filaments*, while many will exhibit those independent and almost intelligent movements that so nearly resemble animal life, and which has caused and is yet causing much discussion among scientists.

The individual cells of the Diatomaceæ containing the protoplastic endochrome are called *frustules* and have an external coating of nearly pure silica, which consists of two portions or *valves*, which are connected at their margins by hoops or bands of variable widths forming a minute box. These siliceous shells or frustules occur in a great variety of beautiful and symmetrical forms, and the valves, or main surfaces of the frustules, are generally richly carved and sculptured, and under the microscope show striæ

pinules, ribs, cells, knobs, bosses, etc., in almost innumerable variety and combinations, and some of the species when properly prepared and mounted are the best known tests of the resolving power of microscope objectives. The valves of one well known species that is quite abundant in most of our western waters, the Amphipleura pellucida, show at the rate of 90,000 to 100,000 lines or striæ to the inch.

DIATOMACEÆ are undoubtedly of comparatively recent geological age, and I find no reliable authority of their having been found below the TERTIARY, although unverified claims have recently been made of the finding of their siliceous remains in the coal formations.

The fossil remains of DIATOMACEÆ abound in the vast sub-plutonic and other strata on the Pacific coast of North America, which exhibit both fresh water and marine species, though rarely in a mixed state. In most of the deposits the predominating species present indicate the character of the water, and the climatic influences under which they were accumulated; different species or groups of species, usually appearing in fresh, brackish, or salt water, and in seas, lakes, rivers and marshes.

While a majority of the fossil diatomaceous deposits hitherto discovered are of fresh water origin, by far the most extensive are marine, and some of them spread over large areas. One of the most important stratums of this character in North America is considered as belonging to the Miocene-Tertiary, and is on or near the Atlantic coast, and is largely in the states of New Jersey, Maryland and Virginia. The principal deposits in Maryland commence at about sixteen feet above tide water, and are covered with four to twelve feet of earth. They then dip below tide water until at Fortress Monroe they are from 200 to 400 feet below the surface, and from an artesian well at Atlantic City, N. J., fossil diatomaceous material containing several new and beautiful species has recently been secured from depths respectively of 406, 510, 535, 550 and 628 feet below the surface.

The extent of some deposits of fossil Diatomaccæ and the vast number and variety of forms contained in them, seem almost incredible, and Dr. Buckland states that the remains of these minute forms have added more to the mass of the exterior crust of the globe than has the bones of animals. Ehrenberg estimated that one of the diatomaceous deposits in Bohemia, covering a large area to an average thickness of some fourteen feet, contained not less than 40,000,000,000 diatoms to the cubic inch, and Mr. Frederick Habershaw, several years ago, published a catalogue of over 4,000 species then known to diatomists.

While the samples of inter-glacial peat submitted for examination were all well filled throughout their entire substance with the siliceous remains of fresh water Diatomaceæ, it is not probable that preparations from the small number of specimens at our disposal, and the consequently small number of slides prepared and submitted to Prof. Smith for examination, will be exhaustive as to the diatomaceous contents of the peat. Accumulations of peat and diatoms, like deposits of more nearly pure diatomaceous material, are probably of very slow growth, and, as is well known to microscopists, the upper layers of a stratum often exhibit different species from those found in the lower, or other parts of the same deposit, which may have been accumulated thousands of years earlier, and under different climatic and other influences, and it is quite probable that a more thorough examination of this very interesting deposit will yield many species which were not on the slides submitted for examination, and consequently are not included in the following very valuable "list of species," and the interesting notes upon them, by that veteran diatomist, Prof. H. L. Smith.

Their value and appropriateness in this connection, fully justifies me in using the paper of Dr. Johnston, with the supplement by Prof. Smith, on the "Preparation and Mounting of Diatomaceæ," which originally appeared in "The Lens,' a journal published by "The State Microscopical Society of Illinois," and which is nearly out of print.

LIST OF SPECIES AND SOME NOTES UPON THEM.

BY PROF. HAMILTON L. SMITH.

The discovery of a peat deposit between two layers of boulder clay in Minnesota, is not only interesting but remarkable, inasmuch as the organisms found in the over and underlying clay are all of marine origin, while those of the deposit, lying between, are not only fresh water forms, similar to those found in the sub-peat deposits of the eastern states, but with one or two exceptions, are forms living at the present time in the great lakes or their tributaries; so that, geologically speaking, the deposit appears to be of very modern origin. While the difference between this and the sub-peat deposits of the eastern states is not very marked, yet a few distinctive species do occur, and will be mentioned in the notes appended to the list, which ally it to the fossil deposits of Oregon, Utah and California, and which, to a practiced eye, would serve to indicate the intermediate position, and to distinguish it

from both. How such a deposit, which is certainly of much more recent origin than the boulder clay, came to be thus interposed, is an interesting question,—a question for the geologist to settle. The thickness of the overlying bedvaries from twenty to thirty feet; this, and the lower bed, like theother boulder clays of Minnesota, show, on careful examination, only marine fossils; whereas, as already mentioned, only fresh water and recent forms are found in the peat deposit. At the request of Mr. B. W. Thomas, I have examined a series of slides very carefully prepared by him, and the result will be found in the following list; these are all fresh water diatoms.

The larger diatoms were many of them broken, owing to the character of the deposit, which contained much sand, but the smaller forms were mainly perfect.

The number of species might have been considerably extended if I had followed the example of some of the European diatomists, and affixed *n. sp.* to each form with a slightly varying outline, striation or size. I have in the list, gone to the fullest extent in this direction which I thought allowable; indeed, the number might be somewhat lessened with advantage.

The almost total absence of Surirelleæ Nitzschieæ Pleurosigmæ and Synedreæ, which abound in many eastern deposits, is a characteristic feature, and also the presence in great abundance of spicules of Spongillidæ, and small, flask-shaped bodies; some of these latter are quite smooth and others reticulated or covered with short spines, and all are rigidly siliceous. Ehrenberg classed them with the Infusoria, and even placed them in different families, calling the smooth forms "Trachelomonas," and the hispid or armed ones "Chætotyphila." I have frequently found these in recent gatherings, and they occur quite abundantly in some sub-peat deposits. *e. g.* Wrentham, Mass., and Smithfield, R. I. I give in the list the average length or diameter of the frustules as they occur in this deposit, also references to where figures illustrating the different species may be found, and in the appended notes will be found remarks on most of the species.

HAMILTON L. SMITH.

DIATOMS FOUND IN INTER-GLACIAL PEAT. MINNESOTA.

*Length.	Ref. No.			Author.	Plate.	Fig.
10	1	Achnanthidium..	flexellum, Breb	Van H	XXVI	30
22	2	Amphiprora......	ornata, Bailey	Van H	XXII BIS	5
12	3	Amphora	ovalis, K..	Van H	I	1
40	4	Campylodiscus ..	clypeus, Ehr	Schmt.....	LV	3
9	5	Cocconeis	lineata, Ehr	Van H	XXX	32
5	6	Cyclotella	kutzingiana, Thwaites	Van H ...	XCIV	4-6
25	7	Cymatopleura	hibernica, W. S	S. B. D....	81	a
7	8	Cymbella	aequalis, W. S	Schmt.....	IX	69
7	9	Cymbella	affinis, K	Van H	II	19
16	10	Cymbella	cistula, Ehr	S. B. D	XXIII	221-a
17	11	Cymbella	cuspidata, K	S. B. D	II	22
17	12	Cymbella	cymbiformis, Ehr	S. B. D ...	XXIII	220
24	13	Cymbella	ehrenbergii, K	S. B. D ...	II	21
23	14	Cymbella	gastroides, K	Van H.....	II	9
51	15	Cymbella	lanceolata, Ehr	S. B. D.....	XXIII	219
8	16	Cymbella	parva, W. S.	S. B. D. ...	XXIII	222
10	17	Cymbella	subaequalis, Green	Van H.....	III	2
7	18	Denticula	elegans, K	S. B. D	XLIX	14-15
6	19	Denticula	tenuis	S. B. D....	XXXIV	293
5	20	Encyonema	caespitosum, K	S. B. D	LV	346-a
9	21	Encyonema	gracile, Ehr	Van H	III	20
22	22	Encyonema	prostratum, Berk	S B. D....	LIV	345-a
12	23	Encyonema	turgidum, Greg	Van H	III	12
7	24	Encyonema	ventricosum, K	Van H	III	16
9	25	Epithemia	alpestris W. S.	S. B. D....	I	7
32	26	Epithemia	gibba, K	Van H	XXXII	1, 2
30	27	Epithemia	granulata, K	S. B. D....	I	3
8	28	Epithemia	ocellata, K	S. B. D....	I	6 a b
14	29	Epithemia	proboscidea, K.-W. S	Van H	XXXI	10
23	30	Epithemia	turgida, Ehr	S. B. D....	I	2
9	31	Eunotia	arcus, Ehr	Van H	XXXIV	2
9	32	Eunotia	arcus var bidens, Gru	Van H	XXXIV	7
15	33	Eunotia	formica, Ehr	Van H	XXXIV	1
7	34	Eunotia	incisa, Greg	Van H	XXXIV	35 a
38	35	Eunotia	major, W. S.—Rab	S. B. D....	XXXIII	286 a
11	36	Eunotia	pectinalis, K	S. B. D.....	XXXII	280 a
3	37	Fragilaria	construens, Ehr	Van H	XLV	26-27
8	38	Fragilaria	virescens, Ralfs	Van H	XLIV	1
5	39	Gomphonema....	abbreviatum, K	Van H ...	XXV	16
14	40	Gomphonema....	acuminatum, Ehr. var. coronata	Van H ...	XXIII	15
20	41	Gomphonema....	brebissonii, K	Van H	XXIII	23
12	42	Gomphonema....	capitatum, Ehr..	Van H	XXIII	7
11	43	Gomphonema...	commutatum, Gru	Van H	XXIV	2
13	44	Gomphonema....	constrictum, Ehr	S. B. D....	XXVIII	236 a
11	45	Gomphonema....	cristatum, Ralfs	S. B. D....	XXVIII	239 a
12	46	Gomphonema....	intricatum, K	Van H	XXIV	28
13	47	Gomphonema....	subtile, Ehr. forma Augusta	Van H	XXIII	14
9	48	Gomphonema....	subtile, var. sagitta, Schuman...	Van H	XXIII	27
7	49	Mastogloia	grivillei, W. S	Van H	IV	20 a
9	50	Mastogloia....	smithii, Thwaites	Van H	IV	13
3	51	Melosira	crenulata, K	Van H	LXXXVIII	19
18	52	Melosira	tympanum, Ehr	....	....	....
13	53	Navicula	acuta, W. S	S. B. D....	XVIII	171
13	54	Navicula	ambigua, Ehr	S. B. D....	XVI	149
12	55	Navicula	ambigua, forma craticularis	Van H	XII	6
15	56	Navicula	amphigomphus, Ehr	Van H	XIII	2
13	57	Navicula	amphirhynchus, Ehr	S. B. D....	XVI	142
12	58	Navicula	bacillum, Ehr	Van H	XIII	9
7	59	Navicula	borealis, Ehr.—K	Van H	VI	3
12	60	Navicula	braunii, Green	Van H	VI	21
24	61	Navicula	cuspidata, K	S. B. D....	XVI	131
32	62	Navicula	cuspidata forma craticularis	S. B. D....	IX	67
40	63	Navicula	dactylus forma maxima, Ehr	Van H	V	1
13	64	Navicula	dicephala, Ehr.(pinularia biceps, Greq	M. J., 1856.	I	28
8	65	Navicula	elginensis, Greg	M. J., 1856.	I	33
20	66	Navicula	firma (Iridis var.), Ehr.—K	Van H.....	XIII	1
6	67	Navicula	frontinalis, Gru	Van H.....	XII	33 b

*Relative length or diameter 1=.0001 inch.

Abbreviations: Van H—Van Heurck's Atlas.
Schmt—A. Schmidt's Atlas.
S. B. D.—Smith's British Diatomaceæ.
M. J.—London Microscopical Journal.

*Length.	Ref. No.			Author.	Plate.	Fig.
18	68	Navicula.........	gastrum, Ehr. (var. styriacea, Gru.)	†D. F. J. L.	A	35
15	69	Navicula.........	hemiptera, Ehr.—K.............	Schmt.....	XLIII	27
15	70	Navicula.........	hitchcockii, Ehr................	Schmt.....	XLIX	35
18	71	Navicula.........	interrupta, W. S..............	S. B. D....	XIX	284
9	72	Navicula.........	laevi-sima. K. (Staawoneis rectangularis, Greg.)...............	M. J.. 1854.	IV	17
14	73	Navicula.......	lata, Breb...	Van H	VI	1
23	74	Navicula.	legumen. Ehr.....................	Van H..	VI	16
22	75	Navicula....	limosa, K..................	Van H.....	XII	8
15	76	Navicula.........	limosa, var. gibberula, K.	Van H.....	XII	19
12	77	Navicula.........	limosa, var. ventricosa, Ehr.—Donk..................	....	XII	24
30	78	Navicula.........	ludloviana, A. S	Schmt	XLVI	15
37	79	Navicula.........	major. K...	Van H.....	V	3
12	80	Navicula.........	mesolepta, Ehr...................	S. B. D	XIX	182
12	81	Navicula.........:	mesolepta, var. stauroneiformis, Ehr. ..	Schmt	XLV	53
50	82	Navicula.........	nobilis. Ehr.—K.	Van H.....	V	2
8	83	Navicula.........	slesvicensis. Gru.................	Van H.....	VII	29
11	84	Navicula.........	trinodis. Lewis....................	‡	2	6 a
28	85	Navicula.........	viridis. K..................	Van H.....	V	5
10	86	Navicula....... .	viridula, K........................	Van H.....	VII	25
21	87	Navicula.........	vulpina. K.	Van H.....	VII	18
5	88	Navicula.........	winchellina, N. Sp. (nav inflata., Donk.)	§D. B. D,:.	III	9
32	89	Nitzschia.........	amphioxys. K.—W. S..............	S. B. D....	XIII	105 c
11	90	Nitzschia.........	thermalis. K..............	Van H.....	LIX	22
81	91	Stauroneis........	acuta. W. S..........	S B. D....	XIX	187
9	92	Stauroneis	anceps, Ehr......................	S. B D ...	XIX	190
23	93	Stauroneis..	gracilis, Ehr......	S. B. D....	XIX	186
61	94	Stauroneis........	phoenicenteron, Ehr..............	S. B. D....	XIX	185
12	95	Stauroneis........	punctata, K —Ehr............	S. B. D....	XIX	189
40	96	Surirella.........	crenulata, Ehr...........		....	
56	97	Surirella.........	splendida, Ehr..............	S. B. D....	VIII	62
80	98	Synedra..........	capitata, Ehr.................	S. B. D....	XII	93
100	99	Synedra	longissima. W. S. ?............	S. B. D....	*XII	95
12	100	Tabellaria.	fenestrata, K	S. B. D....	XLIII	317 a

*Relative length or diameter 1=.0001 inch.
Abbreviations: Van H—Van Heurck's Atlas.
Schmt—A. Schmidt's Atlas.
S. B. D.—Smith's British Diatomaceæ.
M. J.—London Microscopical Journal.
†—Diatomees de Frans Joseph Land.
‡—Notes on new and rare species, 1861.
§—London British Diatomaceæ.

NOTES ON THE SPECIES.

No. 1. Achnanthidium flexellum Breb.=Cocconeis thwaitsii W. Smith. This diatom I found living at Copper Harbor, Lake Superior, and it occurs frequently in fresh water gatherings in the Eastern states. It is flexed in front view (f. v.), has dissimilar valves and a sigmord median line; outline of valve oval, aspect hyaline; not common in the deposit.

No. 2. Amphiprora ornata Bailey. First detected by him in the Croton water, and not uncommon in fresh water streams in the Eastern and Middle states. I have found it in filterings from lakes Erie and Michigan; one gathering from New Jersey has frustules nearly double the normal length. Bailey's figure, from Withlacooche river, Florida, is a rough outline; Mic obs. Smith Cont. 1850, Pl. 2, f. 15. In the list of Croton diatoms he considers it a Paludosa. I have never found it except contorted. The general aspect is hyaline, and the endochrome very delicately colored, and resembling in its arrangement that of a Nitzschia. Not common in the deposit and only broken frustules.

No. 3. Amphora ovalis K. Occurs abundantly in the living form and is cosmopolitan and not uncommon in sub-peat deposits. Ehrenberg describes and figures it as A. gigas in Abb. der Königl. Akad. 1870, from a deposit near Salt lake, Utah, where it is found associated with Surirella crenulata E, our No. 96. Not rare in the deposit.

No. 4. Campylodiscus clypeus E. I found only a few fragments of this diatom in the deposit. It occurs living at Petalume, Cal., and probably may be found in other western localities. I have not observed it in any gatherings from the great lakes.

No. 5. Cocconeis lineata E. Probably a variety of C. placentula, which is found in nearly all fresh water streams and ponds, densely incrusting stems of algæ, leaves of Potamogeton, etc. It is very variable in size; the larger forms are probably sporangial. The valves are generally broadly oval, and unlike: one, the lower, has median line and nodule. Common.

No. 6. Cyclotella kutzingiana. Exceedingly abundant in this deposit and of very variable size. C. meneghiniana is a more undulated form of this, and C. rectangulata is doubtfully distinct. The frustule is undulate in front view, and the valve, in s. v., shows this, especially the larger specimens, by a shaded band across a diameter, or a little one side of a diameter, and it is more or less apparent on all the valves. It is found everywhere living, and is common in almost all sub-peat deposits. Great confusion exists in the species of this genus.

No. 7. Cymatopleura hibernica W. S. This diatom is not very common, though I have found it living in gatherings from lake Erie, and also in fresh water deposits in the Eastern states. It is rare in the Minnesota deposit, and I found no whole frustules.

No. 8. Cymbella aequalis W. S. This pretty little diatom, which resembles a Navicula, is fairly abundant in the deposit. It has somewhat sharper ends than Greville's figure, Ann. & Mag. Nat. Hist. April 1885. Pl. ix, fig. 4. He describes it as having the striæ fine, but not close, and shows them in the figure rather too strongly marked. He found it in a peat deposit. It does not occur very frequently in the U. S., nor do I recollect ever meeting with it in gatherings from the great lakes. It occurs, however, fairly abundant near Richmond, Va.

No. 9. Cymbella affinis K. A small form, common, but not abundant in this deposit. The Cymbelleæ are generally present in all our sub-peat deposits, and occur extensively in the living condition in almost all fresh water gatherings. The distinction formerly made into Cocconema and Cymbella, based on the presence of a stalk or stipe for the former, is now properly abandoned; though Encyonema, generally found in the living condition in tubes, and which otherwise would fall into this genius, is yet retained. There is much confusion among these smaller forms of Cymbelleæ. Thus, I have specimens marked by Brebisson as C. affinis, which are C. ventricosa K.—Encyonema ventricosum, which is also C. ventricosa of Ag. Rut. Diat. Ex. No. 24, and given by Rabenhorst as a brackish species. C. affinis has a curved median line, extending to the extremities of the valve, while that of the Encyonemeæ is straight, or very nearly so.

No. 10. Cymbella cistula E.=Cocconema W. S. This diatom occurs plentifully in the deposit. It is distinguished from C. cymbiformis by being more bent or curved on the ventral margin of the valve, and also distinctly inflated. How far these can be accepted as specific characters is questionable. It is not difficult to find many intermediate specimens.

No 11. Cymbella cuspidata K. Common in this deposit, and varying considerably in size and distinctness of the produced ends. It is allied to No. 13, from which, however, it differs in its smaller size and finer striation. Both these forms are common in fossil deposits and in recent gatherings.

No. 12. Cymbella cymbiformis E. Common, and doubtfully distinct from No. 10, from which it differs only in wanting nearly or quite the inflation on the ventral margin of the valve, and in being much less curved. The striation is about the same.

No. 13. Cymbella ehrenbergii K. A large and fine species, distinguished from No. 11 by its much coarser striation and larger size, as well as sharper ends. It is not rare in this deposit.

No. 14. Cymbella gastroides K. This, and probably numerous other species, constituted by Grunow, Kutzing and Ehrenberg, on slight differences of form or size, is probably but a variety of No. 15. It is not common in this deposit and is distinguished mainly by its blunt ends. C. stomatophora Grun., which is a variety of this diatom, occurs living in the great lakes, and numerous varieties of this and the other Cymbellæ occur in nearly all our sub-peat deposits.

No. 15. Cymbella lanceolata—Cocconema W. S. This form, well figured in S. B. D. Pl. 23, fig. 219, is the same as the typical slide of C. gastroides, Eulensteins series No. 93. It is the largest of the Cymbelleæ found in this gathering, and is pretty abundant, though the frustules are mostly broken. It differs in size and coarser (moniliform) striation, from Nos. 10, 12 and 14, and may be a sporangial form.

No. 16. C., parva I have found conjugating, and the sporangial frustules were C. cymbiformis, and as in the case of Nav. amphigomphus I have actually found the sporangial forms, (and in the same gathering) conjugating and producing the largest frustules, N. iridis. It is quite possible that these larger forms now designated C. lanceolata, and C. gastroides, may be sporangial forms of C. cymbiformis or C. cistula, and that Nos. 10, 12, 14, 15 and 16 are but one species. C. parva is common in this deposit.

No. 17. Cymbella subaequalis Grun. Not common in the deposit, nor have I observed it in any other of the sub-peat deposits, or recent gatherings. Its occurrence therefore though rare in this particular deposit, is interesting. The figure given by Van Heurcks, atlas Pl. III fig.2 is a good representation from specimens found at Brussels. The valve is naviculoid with blunt ends, and distinctly striated.

No. 18. Denticula elegans K.=D. ocellata W. S.; rather rare in this deposit. It is distinguished by the rounded ends of the valves; and the strong pervious transverse costae or ribs, give it the ocellated appearance, which distinguishes it from other species. This form, and the next, with many of the Epithemiae, abounds in the thermal waters of the National Park.

No. 19. Denticula tenuis K. More abundant than the preceding, but not common. It is frequently found in ordinary fresh water gatherings; striation quite conspicuous.

No. 20. Encyonema cæspitosum K. A marked character of this genus, which after all, is but Cymbella living in tubes, while the Cocconemeae slip out and the contracted tube forms a stipe, is this, viz, the median line in the other forms, terminates in the ends of the valves, while in Encyonema, it is nearly straight and terminates within the convex margin of the valves. This is a very conspicuous feature in the larger form, but may be noted also even in the smaller forms like the present one, which is tolerably abundant in the deposit. It is a common recent form.

No. 21. Encyonema gracile E. This is probably the Cymbella scotica W. S. It is a slender and somewhat longer form than the preceding, and more delicately striate and with sharper ends; it is pretty abundant in the deposit.

No. 22. Encyonema prostratum Berk. This is the largest and most robust form, coarsely moniliform striate, and exhibiting in a marked manner the peculiar features of the median line already alluded to. It is not abundant in this deposit, nor indeed in any of our sub-peat deposits. It is not uncommon in recent gatherings.

No. 23. Encyonema turgidum Gregory. This diatom is common in the deposit; it has sharp ends, and is coarsely moniliform striate.

No. 24. Encyonema ventricosum K. Smaller than the preceding; the ends are slightly produced; it is C. affinis of Bret., and C. ventricosa Ag. It is very variable in size; some frustules are smaller than those of No 20, but unlike these latter, they are almost straight on the vertical margin—abundant.

No. 25. Epithemia alpestris, W. S. This is, no doubt, a variety of No. 28, and also E. argus, as already suggested by Dr. Walker-Arnott, Microscopical Journal, Vol. VII, 1859, fig. 174. They are all distinguished in front view by a series of inter-margined ocelli, or foramina, as they are termed by W. S., though they are not openings at all, but siliceous nodules, and from these "eyes" comes the specific name argus. E. alpestris was separated as having produced somewhat recurved extremities, and nearly straight sides in f. v. Not rare in this deposit.

No. 26. Epithemia gibba K. This diatom is not as abundant as the preceding, and the valves are mostly broken. It is quite distinct from the other Epithemiae, for while these latter are adherent by the concave

margin of the frustule, to the stems of confervæ, in the living condition; Epithemia gibba adheres by one end. It is further distinguished by the absence of granules on the valves, as in the other species.

No. 27. Epithemia granulata K. This form is perhaps the most abundant of the Epithemiae in the deposit, and is characterized by its long arched valves and slightly produced ends; and it appears to be somewhat more finely striated and granulated than No. 30, of which, however, it may be a variety.

No. 28. Epithemia ocellata K. The inflated frustules and blunt, not produced ends, served to separate this from No. 25. As already remarked these are features of doubtful specific value. This diatom is much less common in the deposit than No. 25.

No. 29? Epithemia proboscidea K. There appears to be some doubt about the E. proboscidea of W. S. being this form, as the latter is more coarsely marked and the valves are much more arched, and the ends more produced and recurved. The examination of W. Smith's original specimens shows that it is quite distinct from our present form.

No. 30. Epithemia turgida. This is doubtfully distinct from No. 27. Valves somewhat more arched, and apparently, not really, more coarsely granulated, and the ends are somewhat more recurved. It is not as common in the deposit as No. 27.

No. 31. Eunotia arcus E. This is not the Eunotia arcus W. S. which is a very different diatom, but it is Himandidium arcus W. S., a name given to the species of the genus which cohered after self division, forming a a ribbon or filament of frustules, a character considered now of no specific value. E. arcus is very variable in size and outline, it is generally arched, somewhat more convex on the dorsal margin, and has produced ends; the ventral margin is nearly straight and the valve is transversely and conspicuously striated. It is very abundant in the deposit and occurs plentifully in the many sub-peat deposits.

No. 32. Eunotia arcus var. bidens Grun. This variety is common, and is also, like E. arcus, variable in size.

33. Eunotia formica E. differs from No. 31 in having the ventral or concave margin of the valve, sharply undulated at the middle. It is the Himandidium undulatum of W. S. and is not uncommon in the deposit. It is very variable in size.

No. 34. Eunotia incisa Greg. This is a small form, more delicately striated than the preceding, and is rather abundant in the deposit. It occurrs in gatherings and fossil deposits of high latitudes in great abundance. The valves have a decided little notch near the ends, on the concave or nearly straight margin. This notch is, in the other Eunotiæ, replaced by an inter-marginal nodule.

No. 35. Eunotia major W. S.—Himantidium W. S. It is doubtful whether this is anything more than a large variety of E. arcus. It is abundant in the deposit.

No. 36. Eunotia pectinalis K. This diatom is but a variety of E. arcus. It was called Himandidium pectinale by W. S., and the frustules do adhere very firmly; but it differs in no way from E. arcus except to have the dorsal margin of valve flat, or even slightly indented, and it is generally somewhat smaller. Common.

No. 37. Fragilaria construens—staurosira E.—Odontidium tabellaria W. S. Valves small, hyalin, and inflated, sometimes so small as to resemble a small cross, and not unlike small specimens of Tabellaria flocculosa with which it has been confounded; it occurs in filaments of 5 to 10 frustules in the prepared slides, and is not rare. An abnormal form of this, and found only in a single gathering at Ormsby, Eng., wanting one of the arms of the cross, was called by W. Smith Triceratium exiguum; along with it in the same gathering was an abundance of the normal form with both the inflated and the stauriniform valves. It is not rare in both forms in the Minnesota deposit. The inflated valves are Kutzing's Navicula inflata, K. B. Tab. 3 fig. 36. Odontidium parasiticum W. S.=Fragilaria binodis E. is probably this diatom.

No. 38. Fragilaria virescens. Not rare to the deposit, both the valves with constricted ends and filaments of a few frustules.

No. 39. Gomphonema abbreviatum E. This small form is not uncommon in the deposit, the striæ are marginal, and easily seen; it may be a very small form of No. 43. It is difficult to decide whether this is Kutzing's species.

No. 40. Gomphonema acuminatum E. The Gomphonemæ are quite abundant in this deposit; and intermediate forms, between species constituted by Ehrengberg and many of the continental observers, are not rare. The present form, however, is well marked, quite variable in size, and readily recognized. Nos. 47 and 48 are probably slender varieties of the present diatom.

No. 41. Gopmhonema brebisonii K. This, which is a large, well marked variety of the preceding, and is probably same as G. turris E., occurs in considerable abundance in this deposit. It is a marked variety, and possibly a distinct species. It occurs living in the great lakes and their tributaries, as also all the other forms in this list.

No. 42. Gomphonema capitatum E.—G. elevatum E. This diatom is very abundant in the deposit, and also living in the great lakes. A large variety has been called G. herculeanum by Ehrenberg, and G. oregonicum E. and G. giganteum E. are probably varieties, as also Grunow's G. robustum. It is very variable in size in the deposit.

No. 43. Gomphonema commutatum Grun., occurs abundantly in the deposit. I have not observed it living. It is more conspicuously striated than the smaller forms of the preceding: striæ marginal; it is allied to G. vibrio, and except in the somewhat greater breadth of the valve is not to be distinguished from No. 46.

No. 44. Gomphonema constrictum E. The passage from No. 42 into this form is very easy, the capitate head is more constricted and rounded, and intermediate forms are not rare. It occurs in the deposit about as frequently as G. capitatum and is a common form, living in nearly all fresh waters.

No. 45. Gomphonema cristatum Ralfs. This is an intermediate form between the last and No. 40. Not as frequent in the deposit as the latter and generally smaller.

No. 46. Gomphonema intricatum K. Grunow's G. commutatum is allied to this, and G. hebridense of Gregory is probably the same. The striæ are marginal and the central nodule is almost midway from the ends of the valve, in this respect differing from the normal G. commutatum; but intermediate forms are abundant in the deposit.

No. 47. Gomphonema subtile. This is a very slender form of G. constrictum, and so also is No. 48, and both should be considered as varieties.

No. 49. Mastogloia grevillei W. S. This diatom is somewhat rare in the deposit and, so far as I am aware, has not been found in any other of our fossil deposits, or indeed in any gatherings from the western lakes. It is a small, coarsely-marked form, valves with cuneate ends, and the peculiar inflation figured in the British Diatomaceæ, Supp. pl. LXII, fig. 389*a*, on the under surface of the valves near the ends, is quite apparent. The frustules found in the deposit are all smaller than the original, found at Portland hills by Dr. Greville, but otherwise agreeing completely.

No. 50. Mastogloia smithii W. S. This diatom is rarer than the last in the Minnesota deposit. It is, however, a much more common form in fresh water gatherings. As found in the deposit the valves are somewhat narrower and with sharper ends than the normal form. The loculi are conspicuous and the striation much finer than that of M. grevillei.

No. 51. Melosira crenulata K. The absence of Melosireae from the Minnesota deposit is a marked feature, inasmuch as they constitute the larger portion of many of the Oregon, California and other fossil deposits of the Pacific coast, and they occur abundantly, living in all our fresh waters; but few frustules were found of this diatom. It is probably but a variety of M. nichalcea (orthosira) W. S.

No. 52. Melosira tympanum E.? It is somewhat doubtful whether this is the form described by Ehrenberg as occurring in the fossil deposit, Truckee river, California, but the few valves which I have found agree well with his figures.

No. 53. Navicula acuta W. S. Not very abundant in this deposit though not rare.

No. 54. Navicula ambigua E., rather rare in the deposit; the craticulate form is somewhat more abundant; perhaps this may be owing to the striking character of the latter, which makes it so much more conspicuous. These craticulate forms, arise from the persistence of the sporangial sheath which envelops the frustule. The striation on the valves, can be detected in under this. The ribs on the sheath, are much more pronounced in this form, and in No. 61 to which it is closely allied, than in any other of the Naviculeæ. N. brebissonii perhaps comes nearest, and a new genus Perizonium, was constituted to receive the craticulate variety of this diatom, which was called P. braunii. I have observed these rib-like markings in the sporangial sheaths of N. viridis, but none are so conspicuous as these of N. antiqua and N. cuspidata. The genus Stictodesmis of Greville, appears to be founded upon this character, and I have observed it in a small marine form, no ways differing from antiqua. The resemblance of these craticulate markings to those of Surirella, induced W. Smith, in the Birtish Diatomeceae, to figure and describe our No. 62, as Surirella craticularis.

No. 56. N. amphigomphus E. This is a variety of N. iridis E. with wedge shaped ends. The typical N. iridis is precisely like N. firma, No. 66, but larger. It is not rare in the deposit, and, like all the varieties of N. iridis is finely striate, and shows apparently a few intra-marginal lines parallel with the sides of the valve. All the varieties are common in our sub-peat deposits.

No. 57. Navicula amphirhynchus E. This variety of N. iridis, which scarcely differs from N. producta, is characterised by the produced ends. It is not rare in the deposit. The ends of the valve are blunt and there is a blank space around the central nodule.

No. 58. Navicula bacillum E. This small and somewhat hyaline diatom is not rare in the deposit. The valve has round ends and straight sides, and a distinct median line, with a blank space around the central nodule; striation fine. It occurs in many of the eastern sub-peat deposits. I have not observed it living in any gatherings from the great lakes, but it is abundant in some of the fresh water ponds of the New England states, and in fossil deposits from Sweden and Norway. N. bacillaris, Grey is smaller and more finely marked, and is without the central blank space.

No. 59. Navicula borealis E. K. This small and coarsely marked diatom, N. latestriata of Greg., is usually found among damp mosses on trees; it is not rare in the Minnesota deposit.

No. 60. Navicula braunii Grev. A small form, allied to N. gibba, and tolerably abundant in the deposit; the valve is inflated and has constricted and rounded ends; striæ marginal.

No. 61. Navicula cuspidata K. This fine diatom, which occurs plentifully in recent gatherings and in many sub-peat deposits; is not very common in the Minnesota deposit. The craticutale form appears to be somewhat more plentiful, and is a very striking object, and generally a little larger than the diatom as usually met with. As already remarked under No. 54 this form, our No. 62, was called Surirella craticula by W. Smith. The valves are finely but distinctly striate.

No. 63. Navicula dactylus E. Distinguished from N. iridis by its size and coarser pinnæ, and from N. major and N. nobilis by its straight, not inflated sides. Whether these features warrant a new species is questionable. The distinction into Pinnulariæ and Naviculæ, the former having smooth (apparently) ribs, or pinnae, and the latter striæ made up of fine dots (moniliform), is now abandoned, and all are termed Naviculæ. The species mentioned above are very common in sub-peat deposits and in recent gatherings. The marine forms with smooth ribs are comparatively few.

No 64. Navicula dicephala E. This is the Pinnularia biceps of Gregory, who supposed it new, but this name "biceps" had already been given by Kutzing to a different diatom, and as Ehrenberg has, no doubt, given the name "dicephala" to several entirely different forms, one of which is the "dicephala" of W. Smith and our No. 65, perhaps it would be better to adopt Lagerstedt's name and call the present form N. bicapitata. It is a well marked, though not large form, with straight sides and constricted rounded ends, (not unlike a "rolling pin"), it is dictinctly striate, and is fairly abundant in the deposit.

No. 65. Navicula elginensis Greg. This is the N. dicephala of W. Smith; it is smaller than the preceding, and the valve not unlike it in outline; the sides are generally a little incurved, and there is a peculiarity in the appearance of the central nodule, which at once distinguishes it from No. 64, which has a blank space around the nodule, absent in this form. This striation is rather coarse. It is about as abundant in the deposit as No. 64.

No. 66. Navicula firma. This is a smaller form of N. iridis, and not rare in the deposit.

No. 67. Navicula fontinalis Grun. I am not quite certain that this small diatom, which is very rare in the deposit, is Grunow's species. About a third of the length of the valve, the middle portion is blank, giving the impression of a wide stauros.

No. 68. Navicula gastrum E. var. styriaca Grun. This fine diatom, which is not uncommon in the deposit, reminds one at first glance of Stauroneis punctata. It is, however, larger and much more coarsely marked. The ends are produced in this variety, rather more than in the normal N. gastrum, only one specimen of which I observed in the prepared slides. The striæ are absent from the center, much as in Stauroneis punctata. It is a characteristic form in the deposit, and I do not recollect observing it in any other of the sub-peat deposits, or even in any recent gatherings. The normal form of N. gastrum, as figured by Donkin, has been found by Thomas and Chase in the water supply of the city of Chicago, from lake Michigan.

No. 69. Navicula hemiptera E. Not rare in the deposit; it is a small form, striæ marginal, outline of valve like N. iridis, but somewhat narrow in proportion to length.

No. 70. Navicula hitchcockii E. Quite abundant, and rather larger than those which I have found in the eastern sub-peat deposits, or in recent gatherings. It has a hyaline aspect and is allied to the variety of N. limosa, called "gibberula" by Kutzing. The ends, however, and central inflation, sharper; but it must be confessed, that some small forms of N. gibberula, approximate very closely to it.

No. 71. Navicula interrupta W. S. This is not the N. interrupta of Kutzing, which is only a variety of N. didyma E.; we may, therefore, retain W. Smith's name. Really, this species is a staurineiform variety of our No. 64, and exactly like it in every respect, except the central blank space or stauros which characterizes the present form. It is not so abundant in the deposits as No. 64. Nos. 80 and 81 are similar examples.

No. 72. Navicula laevissima K, Stauroneis rectangularis Gregory. A smaller form than N. bacillum, to which it has a remote resemblance, but the margins of the valves are slightly undulate and the striation somewhat coarser, and instead of the circular central blank space there is an arangement of the central striae giving the impression of a sort of stauros. It is fairly abundant in the deposit.

No. 73. Navicula lata Breb. This diatom is somewhat rare in the deposit, and at once recognized by the very course and distant pinnae; N. borealis is probably a very small variety. I have not observed it in any recent gatherings, but it is found in some of the fossil sub-peat deposits of New England.

No. 74. Navicula legumen E. This fine diatom is also rare in the deposit. The valve has three distinct undulations and rounded ends; the striæ are radiate, not reaching the median line, and there is a large central blank space, or pseudo-stauros around the central nodule.

No. 75. Navicula limosa K. This, and its varieties are common in the deposit. It belongs to the N. iridis group, and is distinguished by the inflation at the middle of the valve.

No. 76. Is a variety of the preceding, with smaller and sharper ends and somewhat deeper constirctions.

No. 77. Navicula ventricosa E.—Donk. Smaller than N. limosa, and less inflated, the sides of the valves are nearly straight; it is characterized by having a transverse blank space around the central nodule, and is not as common as Nos. 75 and 76.

No. 78. Navicula ludloviana A. S. This fine diatom has a resemblance to N. peregrina, which, however, is a marine species; it is characteristic of the Minnesota deposit. It is about the size of N. peregrina, but has a larger blank space at the central nodule. It is found in fossil deposits at Shasta, California, and is figured in Schmidt's Atlas; striae radiate conspicuous and not reaching the medium line.

No. 79. Navicula major K. A large form pretty abundant in the deposit, and differing from N. iridis and N. dactylus by having the valve inflated at the middle.

No. 80. Navicula mesolepta E. This is fairly abundant in the deposit. It has three central inflations and is deeply constricted towards the obtuse extremities. It is N. nodosa, E., a form confounded sometimes with N. legumen, and the latter may possibly be a sporangial form of this diatom.

No. 81. Navicula mesolepta var stauriniformis E. Exactly like No. 80, with the exception that this variety has a distinct central blank (stauros). It is not quite as common in the deposit as No. 80.

No. 82. Navicula nobilis E. K. This is a very large form of N. major, and not rare in the deposit, though the frustules are generally broken.

No. 83. Navicula slesvicencis Grun. This diatom is probably a variety of N. viridula, and is pretty abundant in the deposit. The striation in our form is somewhat more radiate than in Grunow's species, and the ends are a little more produced; but in the main it agrees so closely with specimens from Grunow, that I have little hesitation in adopting his name. The valves are slightly inflated and striae distinct.

No. 84. Navicula trinodis Lewis. This is not the N. trinodis of W. Smith, which is very much smaller and has rounded ends, and was considered by Dr. Arnott as Achnanthidium. The present form was first figured by Lewis, in Notes on New and Rare Species of the United States Seaboard. Phil. 1861, Pl. II fig. 6. His figure shows the striæ too plainly, for it has a hyaline aspect, and is not very rare in many recent gatherings. The constrictions are very much deeper, and the ends sharper than in N. gibberula; it is more like N. hitchcockii, but smaller, and more deeply constricted. It is rare in this deposit, but is found in some of the eastern sub-peat deposits.

No. 85. Navicula viridis K. Abundant, and variable in length and breadth; ends of valve round, and sides scarcely inflated; striæ or pinnæ conspicuous.

No. 86. Navicula viridula K. Common in the deposit, and variable in size; valves inflated and with punctured ends. It is one of the commonest of our fresh water forms.

No. 87. Navicula vulpina K. This diatom, which is not rare in the deposit, resembles N. ludloviana, but is somewhat more finely striate and with sharper ends, and wants the central blank space.

No. 88. Navicula winchelliana, n. sp., H. L. S. This small, but well marked diatom, is not very rare in the Minnesota deposit. It has been figured by Donkin Brit. Diat., pl. III, fig. 9, as N. inflata of Kutzing. An examination of Kutzing's figure, on the Santa Fiore deposit in which he

found it, would have shown that Kutzing's diatom was Staurosira construens. The N. inflata of W. Smith is still another form found in the Peterhead deposit, and quite distinct from the present one which Donkin quotes as found in the Lough Mourne deposit. The latter agrees in all respects with our form, and is well figured by Donkin. It is characterised by having the two or three central striæ somewhat stronger or farther apart so as to give the appearance of a pseudo-stauros. No. 253 Cleve and Moller, Nav. viridula, var. ampiceros as figured in Schmidt's Atlas, might probably be mistaken for this, but wants the peculiar pesudo-stauros and is much larger and quite distinct. As the specific name inflata must be retained for W. Smith's form, I name the present one after Prof. Winchell, who discovered the deposit.

No. 89. Nitzschia amphioxys K. W. S. Not rare in the deposit, but very variable in size. The larger ones are generally broken.

No. 90. Nitzschia thermalis. Less abundant than N. amphioxys, and distinguished by the valve having straight or slightly incurved sides and sharply constricted capitate ends. The paucity of Nitzschiæ in this deposit is marked.

No. 91. Stauroneis acuta W. S. Not uncommon in the deposit. The valve has straight or somewhat incurved sides with sharp ends, and presents a rhomboidal aspect; striae distinct. It is found in recent gatherings with the valves adhering somewhat tenaciously into a filament of six or nine frustules, and is not uncommon in sub-peat deposits.

No. 92. Stauroneis anceps E. This is a small form with produced capitate ends, and finely striate, and is sparingly abundant in the deposit. There are intermediate forms between this and the next No, so that it is doubtful whither this is not a variety. The stauros barely extends to the margin of the valve.

No. 93. Stauroneis gracilis E. Much like the preceding but more distinctly striate and longer, ends of valves slightly produced; not capitate. This is really the parent frustule of S. phoenicenteron.

No. 96. Surirella crenulata E. Only a few fragments of this were found. It is quite common in the fossil deposits from Utah, and is figured by Ehrenberg, Abh. der Königh Akad, 1870, T. II, and fig. 6.

No. 97. Surirella splendida E. Fragments only were found of this diatom, but more abundant than the last. It is a very common form in recent gatherings and in sub-peat deposits. No other species of the genus Surirella were observed in the deposit.

No. 98. Synedra capitata E. Broken frustules of this were not rare, and also of the next species.

No. 99. Synedra longissima and possibly of S. radians. They were too fragmentary to decide.

No. 100. Tabellaria fenestrata K. Abundant.

*THE PREPARATION OF DIATOMACEÆ.

BY DR. CHRISTOPHER JOHNSTON.

In all the range of microscopic research there is confessedly nothing which offers more seductive attraction than that department of botany which comprises the *Diatomaceæ*. Apart from the exclusiveness with which the microscopist makes his observations and pushes his inquiries, there are charms which attach to the life, the modes and the extent of the reproduction, and to the vast results which follow the multiplication of these organisms. There is also a pleasing bewilderment in their large variety of form and dimension, from the grosser discoids to the almost infinitely little living chambers; and a perpetual delight afforded by their architectural beauty, and by the marvelous and matchless delicacy of the designs sculptured upon the siliceous skeletons of their frustules. The man of science pauses in his work to pore over the tracery of detail, and the philosophic student exhausts resource to effect combinations in objectives and in oculars which shall serve to bring the "markings" into view and to perpetuate the picture by photography.

However great the interest which life, habits, and reproduction inspire, the structure and configuration of the siliceous part especially command attention; for this flinty framework, resisting time and decay, alone endures, and is a recognizable integral in vast strata of the earth's surface, while the softer organic portion, leaving the character of the diatom to the skeleton, is caught up and utilized in obedience to the law which compels organic matter to incessant action, whether it mount successively higher or fall within the scope of the humblest organism. This animated matter loses its identity, and its relations to particular forms, but the silicified cachet of *Triceratium* and of *Coscinodiscus* is as palpable in the pillared rock or the California stratum as in the recent condition, or in the softer "deposits" of Nottingham, Md., and of Moron, Spain, or in the guano accumulations of the Chincha and other islands.

"Preparation of the "Diatomaceæ" ought strictly to signify the preservation of individuals or groups of these organisms in a permanent way, and their arrangement in a condition suitable for study and future reference. We would begin with the deep sea-soundings and end with animated pool water. It is not our purpose, however, to discuss at present the various devices adapted to

*The Lens, vol. 1, page 197.

accomplish a task so extended; but we desire to point out those methods of isolating the siliceous parts of Diatoms to which experience has given reputation.

It may be worth while to premise by stating—what is, of course, familiar to the student—that the coveted forms are to be met with in a great variety of conditions, either swarming fresh and full of life in pools, ponds or estuaries, clothed in fibres of green, brown or yellow, or clustering together in springs, pullulating in lakes and rivers, or tossed by the waves of the great ocean itself. In some of these situations the Diatomaceæ become and are the pabulum of myriads of beings, in whose bodies, as the *Acalephs*, the *Salpidæ*, the *Molluscs* and the *Holothuridæ*, their siliceous remains are constantly found by the microscopists, who use these and other creatures for their dredgers. They live with and upon other *Algæ*, and are met with in the green ooze of *Confervoids*, and even among the *Muscidæ*.

As ancient or recently fossilized, however, forming strata of considerable thickness, of widely different consistency and density, and not unfrequently of wide-spread geographical distribution, the Diatomaceæ astonish even the workers in science by the extent of their proliferation, and by the uneventful quiet of their living and dying, apparently undisturbed for whole ages in the conditions of their existence. Examples of these tedious and slowly cumulative formations may be instanced in Cassel, in California, in Jutland and in Maryland and Virginia, the latter furnishing so many varieties of configuration and such rare beauty in design and ornamentation. One of these diatoms, the *Heliopelta*, so much admired, has been selected by a distinguished author to grace the front page of his admirable work on the microscope.

It must be apparent that no one procrustean method of securing the prize can be made applicable in the business of "preparation." The extreme delicacy of *Amphipleura* forbids the rough boiling which *Coscinodiscus* invites; the free recent forms of any kind in "pure gatherings" obviously require nothing more than the destruction of the organic part, else the fairy-like embossing, as shown in lines or dots, is blurred, or disappears; while the so-called Diatomaceous "earths" or clays often tenaciously resist the deliverance of the imbedded gems, made adherent by a filmy, glassy cement, the product of time, an alkali, and a portion of the seeming lithophytes of other epochs. A lacustrine deposit may be washed out clean with water, but rock must be softened and sulphate of lime removed by boiling chlorhydric acid.

In general, the business of preparation involves two distinct processes: *first*, the liberation of the diatoms (as we shall henceforth, for convenience, call the siliceous skeletons of the *Diatomaceæ*) from all extraneous matters, with the exception of amorphous silex or some silicates; and, *secondly*, the complete isolation of the diatoms themselves. The former is, at times, toilsome and disagreeable, by reason of acid fumes which arise in its course; the latter is tedious and, like the other, time-consuming. But both call for a clear knowledge of method and precise executive manipulation, and both demand of the operator an intelligent adaptation of means to an end, and the *patience* with which the attainment of the end is made possible.

The simplest methods of cleaning are not always the most easy,—for example, the rescuing of diatoms from among the *Polycystinæ* of Barbadoes,—nor the most complicated always the most difficult, as, for instance, the treatment required by a sulphate of lime guano known here as the "Algoa Bay." Let us, however, attempt to make the several methods distinctly comprehensible, although in so doing we run the risk of emulating the tediousness of "neighbor Verges."

Apparatus and Chemical Material.—Guided by our experience, the following-named articles are recommended as necessary for the work of cleaning and isolating Diatoms, which should be done in a chamber high above the ground, if possible, and not heated in winter by a flue. Hot-water pipes are far better, as affording immunity against dust. We enumerate:

German beaker glasses of different sizes, with a number of small china plates to serve as covers, several large watch-glasses, or shallow glass capsules of like shape; solid glass rods for stirring; small glass tubes or pipettes; a sand bath and an apparatus for heating; nitric acid, chlorhydric acid, sulphuric acid,—all the best "commercial," except the last, which should be "C. P."; carbonate of soda and carbonate of potassa, both C. P.; Atkinson's alcohol, freshly distilled water, and a copious supply of filtered soft water.

For displaying a cleaned sediment with the view of securing individual specimens, a number of glass slides one and a half inches by four inches should be provided; and for the preservation of finished work, or clean diatoms, a score of small bottles, with corks already fitted.

Finally a large camel's-hair pencil; a few slender cane (reed) strips, to serve eventually, when pointed very finely, to pick out single valves; a supply of litmus paper; a glass funnel, and Saxony filter paper, complete the category.

Method to be Employed.—As pure diatoms, guano findings, and diatomaceous earths or clays each require separate modes of treatment, let us first handle a guano specimen, because some of the steps to be trodden may be called fundamental, or we may say they are of very general application; still, they must in certain instances be preluded by others, may not be wholly needed in particular cases, and are of necessity to be followed by supplementary processes demanded by the peculiar nature of the products obtained.

A guano, such as the Chincha or that of Ichaboë, ought to be coarsely sifted to free it from pebbles, feathers, and masses of crystallized substances. The better part is still, however, very heterogeneous, consisting of diatoms in very small percentage, and of much extraneous matter, earthy, salty, and excrementitial. Boiling water dissolves a great part of all these, and should be repeatedly applied to the deposit, and as often suffered to stand after stirring, so as to leave behind the insoluble constituents, among which, of course, are the objects of our search.

The sediment will be materially lessened in bulk by a good boiling in a solution of carbonate of soda, one ounce to the pint, which dissolves much organic as well as some inorganic matter, and, besides, sets free adherent diatoms without injuring their structure. Carbonate of potash, however, is not so free from objection.

The residuum, being drained upon a filter, ought now to be boiled in an equal part dilution of nitric acid for about ten minutes in a beaker glass, the quantity of the fluid being a couple of inches in hight above a half-inch of the matter upon which it is destined to act. Lime not in the form of sulphate, and some other elements, are dissolved out as nitrates, and must be poured off in the solution when cold after standing. Hot water should now be added freely to the sediment and poured off after its subsidence until all acid shall have been removed, whereupon the residuum is to be once more drained upon a filter.

The matter remaining is now ready for pure nitric acid, in which it is to be boiled for five or even ten minutes; after which treatment, and before cooling, the whole must be deluged with hot water. After standing, the supernatant liquor is to be poured off, and the refractory deposit washed clean with cold filtered water, and drained as before stated.

The sediment now much reduced in quantity, is prepared for chlorhydric acid, in which it is to be boiled for the removal of sulphate of lime if in moderate quantity, perhaps of a small percentage of other matter, and of such metallic stains as have resisted the action of the aquafortis. Besides, the chlorine has

bleached such vegetable organic debris as has escaped destruction, so that the sediment, now composed of diatoms, fine sand and siliceous dust, and extraneous vegetable remains, appears of a pale gray color.

When thoroughly washed in filtered or distilled water, and then rendered as free from moisture as possible, either by means of a filter or by gravitation, the deposit must be subjected to the action of sulphuric acid, C. P., which heated to the boiling point carbonizes the vegetable matters, which, in a charred state, blacken the fluids. The removal of this carbon is to be accomplished in the form of carbonic acid by the addition to the still boiling acid of oxygen, which at the very high boiling point of sulphuric acid combines with it, and the gas escapes in ebullition. Nitric acid (NO_5), may be slowly dropped in, one drop a time, (being very careful to protect the eyes, face and clothing from the miniature pyrotechnics that may result), until the black or dusky color gives place to the orange hue of nitrous acid (NO_3), being what is left of the nitric acid that has parted with two elements of oxygen; or else chlorate of potassa in fine powder, after the manner of Bailey, may be very gradually, and in small doses, dropped into the seething liquid. Upon each contact of the powder a vivid explosion takes place as the carbonaceous particles ignite and consume. Chlorine is evolved, to the great annoyance of the operator, and sulphate of potassa is added measurably to the sand and diatoms beneath. But soon all is of pearly whiteness, and the process is at an end.

The task of cleaning is near its accomplishment; for all that remains to be done is the abstraction of the acid and the washing out of the sulphate of potash.

Let the tyro be careful, and manipulate with deliberation; for the rapid admixture of sulphuric acid and water occasions a sudden and considerable rise of temperature. Instead of pouring or drawing off the hot or cooled fluid, we would recommend that a large beaker glass two-thirds full of hot filtered or distilled water be made ready, and that into the water, by very tardy pouring, or even dropping, the acid, and all it contains, be thrown. When cold, or nearly so, the supernatant fluid must be flowed away, which process is facilitated by holding a glass rod against the beaker's edge to guide the stream, and after repeated washings with distilled water in a fresh beaker (for the sulphuric acid clings to the pot-beaker), the diatoms, the sand, and the amorphous silica alone survive. All is now perfectly clean; but the constituents of the white powder must await separation, and this they can do only

in *dilute alcohol*, because the particles mat or adhere irretrievably in water, in which, also, confervoids speedily arise. We *label* the vessel, and we choose our own time for isolating the precious forms, observing, however, that the whole sediment has shrunk within very small dimensions, as we set aside the result of so much labor.

Finally, in reviewing the work done, let us have in mind the intention of each of the acids employed, and remember that NO_5 boils at a moderately high temperature, which, as in other fluids, is increased by the presence of pebbles, bits of glass, or coarse sand; that HC_1 passes into ebullition at a comparatively low indication of the thermometer; and lastly, that the boiling point of SO_1 is very high indeed,—so elevated, in fact, as to jeopardize all inferior glass-ware.

The foregoing process is open to the charge of being time-consuming,—as are all other methods,—but we have invariably found the results to be excellent. The same success is claimed for a different procedure, practiced and recommended by F. G. Stokes,* and which may be here briefly set forth.

"Provide a beaker glass of six or eight ounces capacity, in which place about two teaspoonfuls of guano, and then fill to near the top with a saturated solution of carbonate of soda. Boil for half an hour, wash well with water, and, after standing, pour off the supernatant fluid very close.

Add now of chlorhydric acid two ounces, boil also for a half hour, wash well, and pour off very close once more.

Treat the sediment with one ounce of strong sulphuric acid. Let it act for ten minutes, and then add bicarbonate of soda cautiously, either in solution or suspension. Shake well during effervescence, wash well, and, with great caution, add two ounces of nitric acid. After effervescence, drop in two pinches of chlorate of potash, boil a half hour, or until the deposit becomes white, and, finally, wash the sediment thoroughly."

From what precedes, it must appear that the aim of the operator is the removal of all inorganic substances, either originally soluble or artificially made so, prominent among which is *lime*, and of all organic matters reduced by a destructive process to a soluble or gaseous form. And it is also evident that when certain of these strange elements are known to be absent, such parts of the processes as are applicable to them ought to be omitted, so that fewer steps are necessary to attain the end. Silex, or sand, of course, is not to be regarded in this connection, as it is as insoluble as the Diatoms themselves.

* F. G. Stokes, On Cleaning Diatoms, Quar. Jour. Micros. Science, vol. xv. p. 222.

Suppose we take a clay or earth, that of *Nottingham*, for example. Cretaceous matter forms but a small part of its substance, which consists, in fact, of Diatomaceous skeletons, more or less adherent through the agency of a mortar, probably a silicate of lime, and of fine siliceous particles, or even sand, less closely connected. To disintegrate a mass, let it first be slaked, as it were, by pouring over it a strong solution of carbonate of soda, and when, after a time, the whole falls to pieces in laminæ and in dust, let it be boiled for fifteen or twenty minutes in a quantity of the same solution, and the result will be the reduction of the cement, the formation of silicate of soda and carbonate of lime, and the almost perfect cleaning of the diatoms. The former is removable by hot water and frequent washings; the latter, by boiling in nitric acid; while chlorhydric acid dissolves out any sulphate of lime and, besides, bleaches by the abstraction of unattacked metallic stains. The fine siliceous dust, the torment of diatomists, can only be gotten rid of by elutriation, as will presently be shown, and refractory particles or lumps must be left behind in the washings.

If the reader have followed our *proces raisonne*, he will hardly be at a loss to answer the query, "What are we to do with such clay or rock as the *Monterey?*" some specimens of which we have found to be extremely hard or tenacious. In this instance, again, the difficulty presented is the disintegration of the rock without doing injury to the diatoms. We may make the mass very hot and then drop it into cold water, by which many diatoms will be sacrificed; or else we may slightly warm the specimen, drop it into a strong solution of carbonate of potash, and boil for a time, to be ascertained by the breaking down of the original lump. In the same way, carbonate of soda may be employed, with more safety to the forms in request, but with less general success; while the potash, which is more energetic in decomposing the cement, is very destructive, if not carefully watched, of the very objects we seek.

Once reduced to the state of powder, the rules just enunciated are to be followed.

Before leaving the difficult or troublesome, we feel obliged to notice such guanos as contain sulphate of lime in any quantity, but especially in large proportions. *Algoa Bay guano* (South Africa,) for instance, as furnished us by a reliable person, was found to consist almost wholly of this refractory substance, which required an especial treatment. Being soluble in boiling and hot dilute chlorhydric acid, it was found necessary to boil the Algoa guano in that dilution, and to pour the whole on a filter, whereby the sulphate of lime in solution ran off and deposited on cooling, while

the guano residuum was caught by the filter, to be subjected again and again to the same process as long as it contained the salt of lime. The small portion of decalcified guano was next exposed to the action of NO_5 and HCl, in the usual way, with the result of securing some beautiful *Actinoptychi* and *Aulacodiscus petersii*.

Recent gatherings, unmixed with sand, mud, or other refractory extraneous substances, are not made to pass through the ordeal of an alkali and so many acids as in the case of a guano, but may be cleaned by the use of one of these agents with the aid of no long-continued heat. Chlorophyll will yield to carbonate of soda, and all possible lime here, to nitric acid; but when we have to deal with very delicate *Amphipleuras* or *Grammatophoras*, marked with almost ghostly lines, we should handle our reagents with gloves, and not boil out those exquisite markings which almost rival the art-ruled bands of Nobert. Maceration for a time may be sufficient; or, if the quantity be small, all phytic substance may be burned away by the heat of a spirit-lamp flame applied beneath a film of mica, on which the "once animated dust" reposes, and on which it may, without change, be mounted in balsam.

It is needless to remind the young operator of the necessity for delicacy in all manipulative procedures, and not least in the washings of pure gatherings, or of those containing the filmy forms. But care is especially to be exercised in the recovery of those most fragile diatoms which are met with in *Barbadoes earth*. Water alone, poured *gently* on this polycystinous deposit, will suffice to float away and waft them to slides ready for their reception. And this may be done in a beaker, so that the supernatant water, rendered milky by diatoms and siliceous dust, yields by elutriation the fairest of results.

Isolation of Diatoms:—We have already pointed out the advantage, nay, even the necessity, of preserving the fruits of all cleanings in dilute alcohol, in which they may rest in safety awaiting the separation of the morphous from the amorphous. And we may here add the advice to recommit the diatoms to alcohol finally before mounting, or incidentally, if interruption temporarily arrest the perfect course of the isolation. The methods of Mr. F. Okeden* by decantation, and by whirling in an evaporating capsule or large watch-glass, as suggested by Mr. J. A. Tulk,† we have found to answer every requirement if they be as dexterously managed as they are ingeniously devised. But we would call attention to a point

*Method of Washing Diatomaceous Earths and Clays; Quarterly Journal of Microscopical Science, vol. iii. p. 158.

†On the Cleaning and Preparing of Diatoms, vol. xi. No. 3. III.

not hitherto noticed, incidental to the decantation process, and which has reference chiefly to the discoid forms. It is this: When the diatoms were nearly or quite free from foreign matters, and beaker glasses were being used in the preparation, we observed that entire disks adhered to the flat bottoms of the vessels. We utilized this knowledge by emptying a beaker, by washing it out quite freely with distilled water, and, finally, by detaching and collecting the absolutely perfect diatoms by means of a soft camel's-hair pencil, well cleaned. In this way we have had excellent success with many gatherings, but with none better than the *Nottingham earth*, as was shown by some of our slides exhibited in Chicago at the reunion of the State Microscopical Society of Illinois.

We have now, by whatever process employed, attained the cleaning and separation of the diatoms, and have consigned them to the temporary guardianship of dilute alcohol; but there still remains for us the task of a final preparation of them for mounting. By the plan adopted and suggested by Mr. Okeden they have been "sorted" as to size; yet one washing more is necessary before we can transfer them to the expectant slides. If the diatoms were to be dipped out by a tube directly, and dropped either upon a cover or a slide, the rapid alcoholic evaporation would keep the whole field in agitation, and the objects would eventually group together in drying and materially mar the beauty of the preparation. This defect may be easily remedied by quickly washing out the alcohol; after which the even display of the diatomaceous forms is readily accomplished, especially if we give the end of the slide a fillip with the finger previous to putting it aside to dry spontaneously. At this point the microscopist has the election either of mounting in the *dry way*, or of embalming his tiny treasures in Canada balsam. He may add the balsam drop *au naturel* and gently heat over a spirit flame before applying the cover, or he may omit the evaporation and mount "soft," placing a small screw, for a weight, upon the cover, or he may use balsam thinned by chloroform, or dissolved in absolute alcohol, and filtered as recommended by Dr. Schaeffer, of the Army Medical Museum, and then apply the continuous pressure of a small weight. By the first method the slide will be immediately ready for use when labeled; by the others, a certain number of hours or days must elapse before the margins of the covers will have become securely attached. But the work is done, and the student may now gloat over the things of beauty which he views by the light of science. It is true that he may regret a few forms which have been floated off under the descending cover, but careful manipulation alone will in future pre-

vent this mishap. But how can he imitate the exquisite groupings of the *Diatomaceen-Typn-Platte* of Möller? He may note qual· but he may, with much practice, approximate to the excellence of that wonderfully skillful preparer by arranging his diatoms dry upon a slide or cover previously coated with a thin film of gelatine, and then fixing them by exposure for a moment to the vapor of distilled water. In mounting with balsam the diatoms cannot change position, but the gelatine disappears, and is seen no more forever.

Before closing this paper, perhaps already too long, we deem it germane to the subject to refer to the plan which we have adopted with success in the selection or picking out of particular diatoms. It may not be altogether original, yet it is practical, and may aid the inexperienced.

Nothing is easier than to seize particular diatoms and transfer them to a bottle for future use, or to a slide, provided the field from which we select be rich and clean. Difficulty, however, occurs when forms in any gathering are few and far between. Let such prepared material be spread upon a large slide, covering a space of one inch by two, and let it be filliped as it is set away to dry spontaneously. With a two-third inch objective, search the white field for any diatoms whatever, and, upon finding, encircle each one with a line, made with the point of a match sharpened and moistened, adding near the circle a dot, or cross, or other sign, always appropriated to the same diatom, and of which a tallying record is kept on paper. At leisure one may, without trouble, single out any desired object, pick it off with a fine dampened point of cane (reed), not including the siliceous cuticle, and deposit it, free from injury, in a small drop of distilled water placed in the centre of the slide.

And here we leave our subject, with the remarks that none of the methods proposed can lead to success unless aided by patience, painstaking, the adaptation of means to an end, and by practiced manipulative skill; and that what appears to be present perfection is only to be regarded as one of the widening circles which tend towards, but which never reach, ultimathulan truth.

*ON THE PREPARATION OF DIATOMACEÆ.

BY PROF. HAMILTON L. SMITH.

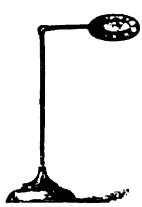
The following paper is intended as a supplement to the very excellent article by Christopher Johnston, M. D., in a former number of this journal, under the above heading, and I know of no better guide for the student. What I have to say relates to the rapid preparation, from crude material, where this has been at all carefully gathered, and to a mode of mounting, *invariably on the cover of the slide*, not mentioned by Dr. Johnston, but which has some great advantages. The gatherings should not be dried, but kept moist, in phials with a little creosote to prevent mould. I very much prefer to examine whole frustules, with both valves adherent, or if filamentous, still cohering. And I have many bottles of preparations for mounting which are nearly as clean as though they had been treated with acids. And many of the most interesting preparations which I have were never boiled in acids. Of course, very much depends upon the skill and carefulness of the gatherer, and a little patience and judgment will enable any one to obtain the crude material tolerably pure. Only a few days ago I made a gathering of *Nitzschiæ*, in which I have the frustules almost as free from foreign matter as though they had passed through the most elaborate acid and chlorate of potassa treatment.

Supposing, then, that one has before him a phial which will hold a considerable quantity of water compared with the sediment in it, the latter composed more or less of diatoms. We proceed thus, and if it has stood for some days perfectly undisturbed so much the better. The bottle is twirled rapidly, and the lighter material rising up in the axis will soon diffuse itself throughout the water. Allowing it to settle for two or three seconds, until to the eye the grosser portions have just been deposited, all that remains floating is now poured off into another phial, and it is from this stock that we are to separate the diatoms and sand from the clay and organic matter. The material poured into this second bottle is allowed to settle until the water simply appears milky or cloudy; the time will vary according to the minuteness of the diatoms, and can only be judged of from experience, say one minute, when all that remains floating must be poured off, and thrown away, unless there are very minute forms which it may be desirable to separate. The phial is again to be filled with rain, or distilled water, (hard or lime water should be strictly eschewed,) and again shaken up. As soon as the heaviest deposit touches bottom, the rest should be

*The Lens. Vol. 2, page 209.

poured off into a third phial, leaving say about one-fourth the amount behind in the second phial. The third phial will now consist mainly of sand and diatoms, with lighter organic matter and pure clay; the last two can be removed by elutriation; for this purpose, fill the phial No. 3 with water, and after well shaking allow it to settle two to five minutes, pour off and throw away the slightly milky water, and repeat the operation, allowing it to settle a somewhat longer time; the operation may be repeated a third time, when particles, suspended after an interval of eight or ten minutes may be poured off. Often, after the first settling of bottle No. 2, the diatoms will rise more pure in the mass by twirling the bottle than by shaking it up. A little practice and care will enable any one to separate certain diatoms, according to size. I had a gathering of *Pleusosigma spencerii* from Scioto river, O., sent to me, but although it had been chlorated, still when a mounting was made, not more than one or two frustules would be in the field of view, the great mass being either smaller forms, or fine fragments of silex; by careful watching and testing the time when the different sizes would remain suspended, I have made from this a preparation, which will show hundreds where before were scarcely any, and which would never be recognized as the same gathering. Supposing now a trial shows us the diatoms tolerably abundant, the trial being made by heating in the manner presently to be described; the phial is filled with alcohol and water, half and half. Some samples of alcohol leave behind a scum after evaporation, especially noticeable after burning in the mode presently to be described, and water which will leave crystals, or any scum, must be avoided; the beauty of the preparation will largely depend upon being particular in this matter.

For mounting diatoms I invariably place a drop of the fluid containing them upon the cover, *never on the slide.* The alcohol and water will spread out on the slide, but will remain heaped up on the round cover,like a plain convex lens. I prepare a little stand, represented in the accompaning wood cut, of quite fine wire(so as not to conduct off too much heat) bent at right angles and inserted into a base; the free end is bent into a ring, and upon this ring is placed a square plate of very thin iron (such as is used for the so-called "tintypes" in photography, with the Japan burned off), held in place by bending the corners of the square over the ring, loosely, to allow expansion, without bending when heated; upon this plate the cleaned cover is placed, and then by means of a pipette, a drop of the alcoholic liquid with the diatoms is placed



upon it, and the spirit lamp applied below. The alcohol takes fire and is allowed to burn out; the flame of the lamp is then placed beneath, and the rest gently boiled, the remaining alcohol escaping during this ebullition causes the diatoms, by this very act, to distribute themselves very evenly over the cover, and all matting is effectually prevented. It is better after one perceives that this even distribution has taken place, not to push the heat so as to make large bubbles again, but to slowly evaporate until dry, after which the full power of the flame must be applied until the iron plate and the glass cover is red hot; at first the mass of diatoms, &c., will become black, but as the organic contents and debris burn away there will finally remain only the silex nearly white. I invariably burn in this manner on the cover, even the specimens which have been prepared with acids, for the diatoms thus treated when mounted appear much sharper and cleaner. The amount of heat, if the diatoms are rigidly siliceous, as most of them are, may be the full power of an ordinary alcohol flame continued for some time, but if they are imperfectly siliceous, care must be exercised in the burning.

I invariably use old balsam for mounting, just as bought from the shops, especially if I wish to have a specimen which will bear immediate handling, or be ready to be sent off soon as mounted. Allowing then the cover to cool, while the slide is being cleaned to receive it, I place a drop of the balsam, which must not be fluid, only viscous, on the middle of the slide, and now *with this* pick up the cover from the little stand where it has been heated. The diatoms will be so fastened by the heating, that but few will flow out from under the cover, if any, in the subsequent treatment. I now hold the slide over the flame of the lamp (which should be much smaller than when used for the burning,) until not only all under the cover is a mass of small bubbles, but until very large bubbles, balsam steam, appear; the flame is removed soon as the bubbles are observed all running to one edge. I press down the cover at this place by a mounted pin and start them in the opposite direction. This may seem unnecessary, but long experience shows that this is the better way to get rid of them; during this the slide is held somewhat obliquely, the cover is kept from slipping by the pin, and if all the bubbles do not disappear, then with a very small flame heat is applied just beneath the obstinate ones, the slide being held slanting, and that part upwards where the bubbles are nearest the edge of the cover. The description is longer than the actual process, and the slide when cool is ready for immediate use. Perhaps I am wedded to old ways, but after

trial of fluid balsams, without heat, I have always come back to the old way; still, for selected diatoms, some of these preparations of balsam are good. If the diatoms are to be mounted dry, always the best way, if for real study, I make a ring of the zinc white in balsam (sold by the opticians), and which in a moment or two is sufficiently hard to receive the cover, *and never runs in;* after standing an hour or two I give a finishing ring of the same, or the usual black varnish on the outside.

I think any one who will adopt the mode of mounting on the cover, and subsequent heating, as above described, whatever may be the rest of the procedure, will never consent to give up this part, since it effects so even a distribution, and such destruction of residual organic matter, and gives such increased brilliancy to the preparations; sometimes, if the acid has not been thoroughly washed out of acid treated specimens, snappy explosions will occur when the alcoholic mixture is heated; of course, the remedy is to pour off, and replace with pure water and alcohol.

VII.

OXIDE OF MANGANESE.

N. H. WINCHELL.

It was through the persevering efforts of Mr. J. N. Stacy that this ore has been discovered at and near Monticello, in Wright county. He first noticed a black substance along the bank of the Mississippi, overlying the gray boulder clay and underlying a thick stratum of gravel and sand. This black substance appeared to be brought to the surface and to be distributed more or less on the slope for a distance of several rods, through the action of spring water which constantly oozed from the bluff at about the same level. On having an analysis made Prof. Dodge reported the following May 26, 1891:

Sand and clay	4 98
Carb. lime	6.86
Carb. magnesia	.85
Oxide of iron	.51
Black oxide of manganese	79.83
Phosphorus	.09
Sulphur	.01
Water of hydration and organic matter	6.87
	100.00

Subsequently considerable examination was made in some of the bogs in the vicinity further west and north, so situated as to presumably constitute the main reservoir, notably for the water seen at the river bank, but also for the principal deposit of the manganese oxide, and, although several analyses were made of a ferruginous sub-peat deposit, no manganese oxide of sufficient purity was found at that time. Several shipments of a few tons each were made from the orignial locality, and the excellence of the product stimulated further exploration. The result has been to demonstrate that in several places a bog manganese exists in con-

siderable quantity, more or less associated with bog iron ore, constituting an ore which is valuable for many uses in the arts. Analyses show manganese oxide ranging from almost nothing to ten per cent., and iron oxide to thirty and forty per cent., with the usual varying accompaniments of carbonate of lime, silica and organic matter. Such an ore is widely distributed through that part of the state, and it is very probable that, if exploration be continued, larger deposits of as great purity as that which is found in limited amount by the bank of the river, and analyzed as above, will be brought to light.

It has also been noticed that some of the iron ore deposits lately discovered on the Mesabi range are accompanied by a noteworthy percentage of manganese oxide, promising to be more valuable as manganese ores than as iron ores.

MUSEUM

SPECIMENS REGISTERED IN THE GENERAL

Serial No.	Obtained. When.		Obtained. Whence.	Name.	Number of specimens
8101	Oct.,	1892	Donation.	Proboscina tumulosa Ulrich	
8102	"		"	" frondosa Nicholson........	
8103	"		"	Mitoclema (?) mundulum Ulrich......	
8104	"		"	Rhinidictya neglecta Ulrich...	
8105	"		"	" minima Ulrich.......	
8106	"		"	" " var. modesta Ulrich...	
8107	"		"	Pachydictya pumila Ulrich...........	
8108	"		"	Arthropora bifurcata Ulrich	2
8109	"		"	" reversa Ulrich.................	3
8110	"		"	Stictoporella dumosa Ulrich...............	Num.
8111	"		"	Nematopora granosa Ulrich...............	
8112	"		"	Helopora mucronata Ulrich.....	
8113	"		"	" harrisi James.	
8114	"		"	Arthroclema striatum Ulrich...............	1
8115	"		"	" cornutum Ulrich...............	1
8116	"		"	" armatum Ulrich	
8117	"		"	Callopora goodhuensis Ulrich....	6
8118	"		"	" dumalis Ulrich	Num.
8119	"		"	" undulata Ulrich.	4
8120	"		"	" pulchella Ulrich.....	3
8121	"		"	" pulchella var. persimilis Ulrich.	2
8122	"		"	Homotrypa separata Ulrich................	2
8123	"		"	" tuberculata Ulrich...............	4
8124	"		" ...	Homotrypella (?) ovata Ulrich............	4
8125	"		"	" rustica Ulrich................	
8126	"		"	Aspidopora elegantula Ulrich	1
8127	"		"	Mesotrypa (?) spinosa Ulrich.....	2
8128	July,	1891	Geol. Survey..	" qubecensis Ulrich...	5
8129	Oct.,	1892	Donation.......	Eridotrypa exigna Ulrich.................	5
8130	"		"	Constellaria varia Ulrich	2
8131	"		"	Nicholsonella pulchra Ulrich.......... ..	1
8132	"		"	Leptotrypa claviformis Ulrich......	1
8133	"		"	Nematopora ovalis Ulrich.	
8134	"		"	Batostoma montuosum Ulrich.............	3
8135	"		"	" varium Ulrich.	1
8136	"		"	" fertile Ulrich.....	3
8137	"		"	" " var circulare Ulrich ...	
8138	July,	1891	Geol. Survey ..	Leptæna unicostata Meek & Worthen......	1
8139	"		" ...	" "	3
8140	Aug.,	1891	" ...	" "	10
8141	July,	1891	" ...	" "	3
8142	"		" ...	" charlottæ Winchell & Schuchert..	1
8143	"		" ...	Rafinesquina minnesotensis Winchell......	12
8144	"		" ...	" " "	5
8145	"		" ...	" " var. inquassa. Sard.	Num.
8146	"		" ...	" "	5
8147	"		" ...	" "	Num.
8148	"		" ...	" "	6
8149	"		" ...	" " (?)	1
8150	"		" ...	" " (?)	5
8151	"		" ...	" alternata Emmons............	11
8152	"		" ...	" "	1
8153	Aug.,	1891	" ...	" "	5
8154	July,	1891	" ...	" "	3
8155	Aug.,	1891	" ...	" " var. loxorhytis Meek	13
8156	July,	1891	" ...	" kingi Whitfield............ ...	2
8157	"		" ...	" deltoidea Conrad.	20
8158	"		" ...	" "	3
8159	Aug.,	1891	" ...	" "	4
8160	"		" ...	" "	4
8161	"		" ...	" "	5
8162	"		" ...	" "	5
8163	"		" ...	" "	6
8164	"		" ...	" "	3
8165	"		" ...	Plectambonites gibbosa Winch. & Schuch't	6
8166	"		" ...	" "	2
8167	July,	1891	" ...	Strophomena incurvata Sheppard..........	1
8168	"		" ...	" "	5
8169	"		" ...	" "	12
8170	"		" ...	" "	5
8171	"		" ...	" "	9
8172	"		" ...	" "	26
8173	"		" ...	" "	4
8174	"		" ...	" "	1

ADDITIONS.

MUSEUM SINCE THE LAST REPORT.

Locality.	Formation.	Collector and Remarks.
Cannon Falls, Minn	Tr'nt'n shales	E. O. Ulrich.
Cincinnati, Ohio	Hudson River	"
Cannon Falls, Minn	Trent. shales	"
Near Danville, Ky	Trenton	"
Cannon Falls, Minn	Galena shales	"
"	"	"
"	"	"
St. Paul, Minn	Trenton	"
"	Galena shales	"
"	Trenton	"
Near Cannon Falls, Minn	Galena shales	"
"	"	"
Waynesville, Ohio	Hudson River	"
Minneapolis, Minn	Trenton	"
"	"	"
Near Cannon Falls, Minn	Galena shales	"
"	"	"
St. Paul, Minn	Trenton	"
"	"	"
"	"	"
Near Cannon Falls, Minn	"	"
Minneapolis, Minn	"	"
Near Cannon Falls, Minn	"	"
"	Galena shales	"
Richmond, Ind	Hudson River	"
St. Paul, Minn	Galena shales	"
Minneapolis, Minn	Trenton	"
Decorah, Iowa	Galena shales	C. Schuchert.
Near Cannon Falls, Minn	"	E. O. Ulrich.
"	"	"
Murfreesboro, Tenn	Trenton	"
Minneapolis, Minn	"	"
Near Cannon Falls, Minn	Galena shales	"
"	Trenton	"
Minneapolis, Minn	"	"
St. Paul, Minn	"	"
"	"	"
Near Granger, Minn	Hudson River	Scofield & Schuchert.
Graf, Iowa	"	C. Schuchert.
Spring Valley, Minn	"	Scofield & Schuchert.
Iron Ridge, Wis	"	C. Schuchert.
West Side, St. Paul, Minn	Trent. shales	"
McGregor, Iowa	"	"
Decorah, Iowa	"	"
Mineral Point, Wis	Upper Buff	"
Rockton, Ill	L. blue beds	"
Janesville, Wis	"	"
4 miles north of Beloit, Wis	"	"
Preston, Minn	Trent. shales	Scofield & Schuchert.
12 m. S. of Cannon Falls, Minn	Galena shales	"
"	"	"
Preston, Minn	Trent. shales	"
6 mi. S. of Cannon Falls, Minn.	Galena shales	"
Mineral Point, Wis	Upper buff	C. Schuchert.
Spring Valley, Minn	Hudson River	Scofield & Schuchert.
Iron Ridge, Wis	"	C. Schuchert.
Oshkosh, Wis	Galena	"
Dubuque, Iowa		"
Weisebach's dam nr. Spring Val.	"	Scofield & Schuchert.
Near Hamilton, Minn [Minn	Top of Galena	"
Mantorville, Minn	Galena	"
Near Granger, Minn	Hudson River	"
Bellville, N Y	Trenton	
3 mi S of Cannon Falls, Minn	Galena	Scofield & Schuchert. 50 ft. above base.
3 & 5 m. S. of Cannon Falls, Minn.	"	" "
Mantorville, Minn	"	"
Dodgeville, Wis	Trenton	C. Schuchert.
McGregor, Iowa	Trent. shales	"
Decorah, Iowa	"	"
Mineral Point, Wis	Trenton	"
4 mi. N. of Beloit, Wis	L blue beds	"
Janesville, Wis	"	"
Mineral Point, Wis	"	"
Rockton, Ill	"	"

MUSEUM

SPECIMENS REGISTERED IN THE

Serial No	Obtained. When.	Obtained. Whence.	Name.	Number of specimens
8175	Aug., 1891.	Geol. survey...	Strophomena incurvata Sheppard	9
8176	"	"	" " "	11
8177	"	"	" " "	2
8178	"	"	" " "	6
8179	July, 1891.	"	" trentonensis Winchell & Schuchert	2
8180	"	"	" winchelli Hall	2
8181	Aug., 1891.	"	" trentonensis (?) Win. & Schuchert.	3
8182	"	"	" trentonensis Winchell & Schuchert	7
8183	"	"	" "	4
8184	July, 1891.	"	" rugosa Rafinesque.	12
8187	Aug., 1891.	"	" fluctuosa Billings..................	13
8188	"	"	" "	3
8189	"	"	" trilobata Owens....................	3
8190	"	"	" "	2
8191	July, 1891.	"	" planodorsata Winch'll & Schuchert	1
8192	Aug., 1891.	"	" billingsi Winchell & Schuchert	2
8193	"	"	" scofieldi Winchell & Schuchert.....	11
8194	"	"	" "	2
8195	July, 1891.	"	" "	1
8196	Aug., 1891.	"	Rhynchotrema capax Conrad..............	14
8197	July, 1891.	"	" "	10
8198	"	"	" "	22
8199	"	"	" "	8
8200	"	"	" perlamellosa Whitfield........	2
8201	"	"	" anticostiensis Billings	16
8202	"	"	" "	10
8203	"	"	" "	4
8204	"	Donation ...	" ainsliei Winchell	3
8205	Aug., 1891.	Geol. survey...	" "	1
8206	"	"	" "	5
8207	July, 1891.	"	" "	1
8208	Oct., 1892..	Donation	Escharopora confluens Ulrich......	
8209	Aug., 1891	Geol. survey...	Rhynchotrema inæquivalis Castelnau.....	4
8210	"	"	" "	18
8211	"	"	" "	12
8212	July, 1891.	"	" "	3
8213	"	"	" "	10
8214	"	"	" "	7
8215	"	"	" "	4
8216	"	"	" "	4
8217	"	"	" "	Num.
8218	Aug., 1891.	"	" "	"
8219	"	"	" "	5
8220	"	"	Zygospira recurvirostris Hall var. Minne-	Num.
8221	"	"	" " .[sotensis W & S	10
8222	"	"	" "	34
8223	July, 1891.	"	" "	3
8224	Dec., 1891..	Donation	" "	Num.
8225	"	"	Raufella palmipes Ulrich................	1
8226	July, 1891.	Geol. survey...	Strophomena winchelli Hall..............	1
8227	Aug., 1891.	"	Zygospira uphami Winchell & Schuchert..	10
8228	"	"	" modesta (Say) Hall....	1
8230	"	"	Anastrophia (?) scofieldi Win. & Schuchert	28
8231	"	"	" hemiplacata var. rotunda W & S	1
8232	"	"	" hemiplicata Hall..........	5
8233	"	"	" "	2
8234	"	"	" "	2
8235	"	"	" "	2
8236	"	"	" "	3
8237	Jan., 1892..	Donation	Hallella saffordi Winchell & Schuchert....	4
8238	Aug., 1891.	Geol. survey...	" nicolleti Winchell & Schuchert.	3
8239	"	"	" nicolleti Winchell & Schuchert.	Num.
8240	Feb., 1892	Donation	Aulopora trentonensis Win. & Schuchert..	1
8241	Sept., 1892.	Exchange	Pleurotomaria sphærulata	5
8242	"	"	tabulata................................	1
8243	"	"	Bellerophon montfortianus..................	7
8244	"	"	Polyphemopsis peracuta..............	3
8245	"	"	Nucula ventricosa..........................	3
8246	"	"	Lophophyllum proliferum.	5
8247	"	"	Spirifera camerata.........................	1
8248	"	"	Athyris subtilita..........................	5
8249	"	"	Diplodus compressus........................	1
8250	"	"	Head of Coelacanthus elegans	1
8251	"	"	Eurylepsis minimus.........................	1

ADDITIONS—*Continued.*

GENERAL MUSEUM SINCE THE LAST REPORT.

Locality.	Formation.	Collector and Remarks.
Preston, Minn	Tr'nt'n shales	Scofield & Schuchert.
Fountain, Minn	"	"
St. Paul, Minn	"	C. Schuchert.
Minneapolis, Minn	"	J. C. Kassube.
4 miles N. of Beloit, Wis	L. blue beds	C. Schuchert.
Janesville, Wis	"	"
Kenyon, Minn	Galena shales	W. H. Scofield.
6 miles S. of Cannon Falls, Minn	Top Tr. shales	Scofield & Schuchert.
2 miles S. of Cannon Falls, Minn	Tr'nt'n shales	"
Iron Ridge, Wis	Hudson River	C. Schuchert.
Spring Valley, Minn	"	Scofield & Schuchert.
Near Granger, Minn	"	"
Mantorville, Minn	Galena	"
3 miles S. of Cannon Falls, Minn	"	" 50 ft. above base.
Iron Ridge, Wis	Hudson River	C. Schuchert.
Fountain, Minn	Galena shales	Scofield & Schuchert.
2 miles S. of Cannon Falls, Minn	"	"
St. Paul, Minn	Top Tr. shales	C. Schuchert.
4 miles N. of Beloit, Minn	L. blue beds	"
Spring Valley, Minn	Hudson River	Scofield & Schuchert.
Graf, Iowa	"	C. Schuchert.
Iron Ridge, Wis	"	"
Near Clifton, Wis	"	"
Iron Ridge, Wis	"	"
Graf, Iowa	"	"
Iron Ridge, Wis	"	"
Near Clifton, Wis	"	"
Rochester, Minn	Tr'nt'n shales	N. Ainslee.
Preston, Minn	"	Scofield & Schuchert.
Chatfield, Minn	"	"
McGregor, Iowa	"	C. Schuchert.
Minneapolis, Minn	"	E. O. Ulrich.
10 mil's S. of Cannon Falls, Minn	Galena shales	Scofield & Schuchert, 50 feet above base.
Warsaw, Minn	"	W. H. Scofield.
Fountain, Minn	"	Scofield & Schuchert.
Neenah, Wis	Galena	C. Schuchert.
Oshkosh, Wis	"	"
Janesville, Wis	L. blue beds	"
Mineral Point, Wis	"	"
McGregor, Iowa	Tr'nt'n shales	"
Decorah, Iowa	"	"
6 miles S. of Cannon Falls, Minn	Galena shales	Scofield & Schuchert.
Warsaw, Minn	"	"
2 miles S. of Cannon Falls, Minn	"	"
6 miles S. of Cannon Falls, Minn	"	"
Near Fountain, Minn	Tr'nt'n shales	"
Oshkosh, Wis	Galena	C. Schuchert. [growth.
St. Paul, Minn	Tr'nt'n shales	" Specimens in all stages of
Minneapolis Minn	"	" Lake street bridge.
Oshkosh, Wis	Galena	"
Weisebachs dam, n'r Spr'g Val'y	"	Scofield & Schuchert.
Spring Valley, Minn	Hudson River	"
6 miles S. of Cannon Falls, Minn	Galena	"
5 miles S. of Cannon Falls, Minn	"	"
12 miles S. of Cannon Falls, Minn	"	"
Weisbach's dam	"	" Near Spring Valley.
Near Fountain, Minn	"	"
Preston, Iowa	"	"
Decorah, Iowa	"	C. Schuchert.
Lebanon, Tenn	Glade l'm'st'n	"
Decorah, Iowa	Tr'nt'n l'mstn	"
Near Fountain, Minn	"	Scofield & Schuchert.
Near Cannon Falls, Minn	Tr'nt'n shales	C. Schuchert.
Richmond, Ohio	L. coal Meas.	Sam Huston.
"	"	"
"	"	"
"	"	"
"	"	"
"	L. b'r'en co'l M	"
"	"	"
Linton, Ohio	L. coal Meas.	"
"	"	"
"	"	"

MUSEUM

SPECIMENS REGISTERED IN THE

Serial No.	OBTAINED. When.	OBTAINED. Whence.	NAME.	Number of specimens
8252	Feb'y, 1892	Donation..	Scenidium halli Safford	2
8253	Dec., 1891	"	Strophodonta perplana Conrad	1
8254	"	"	Chouetes pusillus Hall	2
8255	"	"	Spirifer pennatus Owen	1
8256	"	"	Strophodonta nacrea Hall	1
8257	"	"	Orthis vanuxemi Hall	2
8258	"	"	Spirifer parryanus Hall	1
8259	"	"	Atrypa reticularis Linne	2
8260	"	"	Atrypa hystrix Hall	2
8261	"	"	Orthis suborbicularis Hall	3
8262	"	"	Strophodonta demissa Conrad	1
8263	"	"	Orthis iowensis Hall	2
8264	"	"	Cyrtina hamiltonensis Hall	1
8265	"	"	Heliophyllum halli	1
8266	"	"	Favosites alpenensis Winchell	1
8267	"	"	Cystiphyllum americanum Edwards and Haime	1
8268	"	"	Phyllipsastrea gigas ?	1
8269	"	"	Cyathophyllum davidsoni Rominger	1
8270	"	"	Stromatopora	1
8272	"	"	Streptelasma rectum Hall	2
8273	"	"	Mont culipora.	1
8276	July, 1891	Geol. Survey	Orthoceras multicameratum emmons	1
8277	"	"	" "	2
8278	Aug., 1891	"	" "	1
8279	July, 1891	"	Actinoceras beloitense Whitfield	3
8280	"	"	Orthoceras junceum Hall	4
8281	Aug., 1891	"	" "	4
8282	"	"	" "	5
8283	July, 1891	"	" bilineatum Hall	1
8284	Aug., 1891	"	" "	2
8285	July, 1891	"	" amplicameratum Hall	3
8286	Aug., 1891	"	" " "	2
8287	"	"	" " "	1
8288		Donation	" planoconvexum "	1
8289	July, 1891	Geol. Snrvey	Triptoceras	1
8290	"	"	Orthoceras anellus Conrad	1
8291	"	"	" olorus Hall	2
8292	"	"	" "	1
8293	Aug., 1891	"	Gonioceras (?) confertus Winchell and Schuchert	2
8294	"	"	Cyrtoceras mannitobense Whiteaves	6
8295	"	"	" "	1
8296	"	"	" "	1
8297	"	"	Orthoceras bilineatum Hall	1
8298	July, 1891	"	Gonioceras anceps Hall	1
8299	1891	Donation	Triptoceras planodorsatum Whitfield	1
8300	July, 1891	Geol. Survey	Oncoceras pandion Hall	[illegible]
8301	Aug., 1891	"	" "	1
8302	"	"	" "	1
8303	July, 1891	"	" plebium ? Hall	1
8304	"	Donation	" "	1
8305	Aug., 1891	Geol. Survey	Dekayella prænuntia Ulrich	3
8306	"	"	" " var. multipora Ulrich.	1
8307	Oct., 1892	"	" " var. simplex Ulrich	
8335		"	Cypricardites sardesoni Ulrich	1
8379	Sept., 1892	Donation	Monotrypa intabulata Ulrich	1
8380	"	"	Ceramoporella inclusa Ulrich	1
8381	"	"	Ceramophylla frondosa Ulrich	6
8382	1884	By purchase.	Trochonema beachi Whitfield	5
8383	1876-1879	Geol. Survey	" "	12
8384	1880	Donation	" "	2
8385			" "	2
8387	Aug., 1877	Geol. Survey	" "	1
8388			" "	
8389			" umbilicatum Hall	1
8390			Fusipira ventricosa Hall	
8391			" subfusiformis Hall	
8392	July, 1891	Geol. Survey	Schizotreta minutula W. and S.	

ADDITIONS.—*Continued.*

GENERAL MUSEUM SINCE THE LAST REPORT.

Locality.	Formation.	Collector and remarks.
Lebanon, Ohio	Glade l'mst'n.	C. Schuchert.
Rock Island, Ill	Hamilton	J. A. Udden.
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	Corniferous	"
" "	Hamilton	"
" "	Corniferous	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	Hamilton	"
Mineral Point, Wis	L. blue beds	C. Schuchert.
Beckton, Ill	U. buff beds	"
Rockdell P. O., Minn	Galena.	Scofield and Schuchert.
Janesville, Wis	L. blue beds	C. Schuchert.
"	"	"
Near Fountain, Minn	Galena shales	Scofield and Schuchert.
" "	Trenton "	" "
Decorah, Iowa	" "	C. Schuchert.
Warsaw, Minn	Galena "	W. H. Scofield.
Mineral Point, Wis	L. blue beds	C. Schuchert.
Near Rochester, Minn	Galena	W. H. Schofield.
Preston, Minn	L. Galena	Scofield and Schuchert.
Cannon Falls, Minn	Trenton limestone	W. H. Scofield.
Mineral Point, Wis	L. blue beds	C. Schuchert.
McGregor, Iowa	Trenton sh'l's	"
Janesville, Wis	L. blue beds	"
Mineral Point, Wis	"	"
Stewartsville, Minn	Mid'le Galena	Scofield and Schuchert, of Stewartsville. The largest specimen donated by F. L. Wood.
" "		
Mantorville, Minn	"	Scofield and Schuchert.
Pleasant Grove, Minn	"	" "
Near Fountain, Minn	Trenton sh'l's	"
Mineral Point, Wis	L. blue beds	C. Schuchert.
Minneapolis, Minn	Trenton limestone	H. V. Winchell.
Janesville, Wis	Lower bluff	C. Schuchert.
Preston, Wis	Trenton sh'l's	Scofield and Schuchert.
Minneapolis, Minn	Trenton limestone	
Janesville, Wis	L. blue beds	C. Schuchert.
Minneapolis, Minn	Trenton limestone	H. V. Winchell.
Preston, Minn	Trenton sh'l's	Scofield and Schuchert.
"	"	" "
Minneapolis, Minn	"	E. O. Ulrich.
"		
2 m. S. E. of Cannon Falls, Minn	Galena shales	E. O. Ulrich.
Near Fountain, Minn	Trenton	"
St. Paul, Minn	"	"
Minneapolis, Minn		Wm. Howling. (5675).
		C. L. Herrick. (5108).
		H. V. Winchell. (5063).
"		
"		C. L. Herrick. (773).
"		(6867).
Kenyon, Minn		N. H. Winchell.
Lime City, Minn		"
Decorah, Iowa		C. Schuchert.
Granger, Minn	L. Hudson R.	"

MUSEUM

SPECIMENS REGISTERED IN THE

Serial No.	Obtained.		Name.	Number of specimens
	When.	Whence.		
8393	....	....	Fusispira nobilis Ulrich and Scofield.......	....
8394	....	....	" vitata Hall.......................	1
8395	....	....	" vaticina Ulrich and Scofield.....	1
8396	....	....	" convexa Ulrich and Scofield.....	....
8427	Sept., 1880	Geol. Survey...	Trochonema umbilicatum Hall.............	....
8428	1884	By purchase...	" beachi Whitfield.............	....
8429	Oct., 1892	Donation........	Pachydictya occidentalis Ulrich...........	4
8430	Oct., 1892	Donation.......	Rhinidictya paupera Ulrich.................	5
8431	"	"	Escharopora limitaris Ulrich	3
8432	"	"	Callopora ampla Ulrich	4
8433	"	"	Callopora crenulata Ulrich	2
8436	Aug., 1891	"	Asaphus gigas DeKay	1
8437	"	"	Asaphus megistus Locke	1
8438	"	"	" " "	1
8439	July, 1891	Geol. survey...	Lingula modesta Ulrich	3
8440	"	" ...	Maclurea cuneata Whitfield	22
8441	....	" ...	" " "	1

ADDITIONS.—*Continued.*

GENERAL MUSEUM SINCE THE LAST REPORT.

Locality.	Formation.	Collector and remarks.
Decorah, Iowa...................	....	C. Schuchert.
Fountain, Minn...	....	Scofield and Schuchert.
Petit's mill, Mantorville, Minn.	....	N. H. Winchell.
Decorah. Iowa...................	....	C. Schuchert.
Lime City, Minn.................	....	N. H. Winchell. (4104).
Minneapolis, Minn...............	....	Wm. Howling. (5675).
St. Paul, Minn..................	Trenton	....
St. Paul. Minn..................	Trenton	E. O. Ulrich.
Minneapolis, Minn..........	"	"
Near Cannon Falls, Minn.......	Galena shales	"
St. Paul, Minn..................	Trenton	" [natural mould.
Granger, Minn.	Hudson river	R. H. Hesse, gutta-percha impression of
" "	"	" gutta-perc. imp. of nat. mould
" "	"	"
" "	L. Hudson R	Scofield and Schuchert.
Lime City, Minn................	....	N. H. Winchell.
" "	....	"

Additions to the Library Since the Report for 1890.

A

Albany. Geol. Survey of N. Y. Paleontology, vol. xiii. An. Rep. viii-x.
N. Y. State Museum, An. Reps. 43 and 44.

Austin. Geol. Survey of Texas. Second Report of Progress, Bulletins 2 and 3.
Geol. Survey of Texas. Bulletins 1-3; Second Report of Progress: Third Annual Report for 1891.

Avon. American Antiquarian, vol. xiv, No. 5, Sept. 1892.
American Antiquarian vol. xiv, No. 6, Nov. 1892.

B

Baltimore. Amer. Chem. Jour, xiii, 7, 8; xiv, 1-5; Johns Hopkins Univ. An. Rep. xvi; Biol. Lab. Studies v, 1; Circulars ix, 80, 81; x 84, 87, 88; xi 92-99;
Johns Hopkins Univ. Circulars, vol. xi, No. 100. July 1892.
Johns Hopkins Univ. Circulars, vol. xii, No. 101, Nov. 1892.
Amer. Chem. Jour., vol. xiv, No. 6. Oct. 1892.
Amer. Chem. Jour., vol. xiv, No. 7. Nov. 1892.
Amer. Chem. Jour., vol. xiv, No. 8. Dec. 1892.
Johns Hopkins Univ. Circulars, vol. xii, No. 102, 1893.

Basel. Naturforschenden Gesellschaft Verhandlungen ix, 2.

Berlin. Verhandl. Gesellschaft fur Erkunde, Band xix, Nos. 2, 3, 4, 5, 1892.
Gesellschaft fur Erkunde Zeitschrift xxvi, 4-6. Verhandlungen xviii, 7-10; xix, 1.
Zeitschrift Gesellschaft fur Erkunde, Band xxvii, Nos. 1, 2, 1892.

Bern. Mitt. Naturf. Gesellschaft, Nos. 1, 265-1268, 1891.

Bonn. Naturhistorischen Vereins der Rheinlande, Westfalens, und des Regbezuks osnabruck, Verhandlungen, viii, 5.

Boston. Proc. Amer Acad. Art and Science. 1890-91.
" New England Magazine. N. S. iii, 6; iv, 2; old series ix, 6.

Bologna. Memorie della R. Accademia delle Scienze dell Instituto. Serie v, Tomo i. 1891.

Bridgeport. List of birds found in the vicinity of Bridgeport.

Brunn. Verhandl. Naturf. Vereines, band xxix. 1890.
Bericht Meteorology Commission Naturf. Vereines Beobachtung im Jahre 1889.

Bruxelles. Soc. Etomologique deBelgique, Compte-Reudu Series, iv, 15-25.

C

Cambridge. Peabody Museum of Amer. Archeology and Ethnology. An. Rep. xxii, 3, 4.
Harvard Coll. Mus. Com Zool. Bulletin xxiii, 4. 1892.
Mus. Com. Zool. Harvard Coll. An. Rep. of Curator, 1891. Bulletins xxii, 1-4; xxiii, 1, 2.

Champaign. Bulletin Ill. State Lab. Nat. Hist., vol. iii, Article xiii, 1892.
Biennial Rep. of Director of Ill. State Lab. Nat. Hist. for 1891-92.
Chapel Hill. Elisha Mitchell Sci. Soc. Jour. viii, 1, 2, v 2.
Chicago. The Brickmaker, ix, 5.
World's Columbian Exposition. Plan and Classification. 1892.
Christiania. Jahrbuch des Norwegeschen Meteorologischen Instituto fur 1890.
Norwegian North Atlantic Expedition. Zoology. Crinoida und Echinoida. 1892.
Chur. Jahresb. Naturf. Gesellschaft Granbundens fur 1890-91, xxxv Jahrgang.
Cincinnati. Soc. Nat. Hist. Jour., xiv, 3, 4; xv, 1.
Soc. Nat. Hist. Jour., xv, 2. July 1892.

D

Darmstadt. Vereins fur Erdkunde. Notizblatt, iv, 12.
Abhandl. Geol. Landesanstalt, Band ii, Heft 2. 1892.
Abhandl. ii, Geol. Landesanstalt.
Denver. State School of Mines. An. Rep. 1885, 1889. Biennial Rep. 1886, 1890. Building Stones of Colorado, 1884. Catalogue, 1890-91.
Colorado Scientific Society, Proceedings, iii, 3.
On the ore deposits of Newman Hill, near Rico, Col.
The Nature of the Chemical Elements.
Geology of Colorado Ore Deposits. 1888
Fuel Resources of Colorado. 1890.
The Post-Laramie Beds of Middle Park, Col., by Whitman Cross. Proc. Col. Sci. Soc. 1892.
Dublin. Royal Dublin Soc. Sci. Proc. vi, 6-10; vii, 1-2; Sci. Trans. iv, 6-8.
Royal Dublin Sci. Soc. Proc., vol. vii, pt. 4.
Sci. Trans. Roy. Dub. Soc., Vol. iv, Art. ix, xiii. July-Dec., 1891.
Sci. Proc. Roy. Dub. Soc., Vol. vii, Pt. iii. March, 1892.

E

Edinburgh. Trans. Edinburgh Geol. Soc., Vol. vi, Pt. iii. 1892.
Proc. Roy. Soc. of Edinburgh, Vol. xviii. Session 1890-91.
Erlangen. Sitzungsb. Physik-medicin Societat xxiv. Heft, 1892.

F.

Frankfort. Geol. Sur. of Ky. Rep. on Geol. of parts of Jackson and Rockcastle Co's. Rep. on Petroleum and Natural Gas in Western Ky.

G

Gera. Jahresb. Gesell. Freunden Naturw., 24th and 25th, 1889-1892.
Giessen. Bericht Oberhess Gesell. fur Natur-und. Heilkunde xxxiii 1892.
Glasglow. Philos. Soc. Proc., xxii, 1890-91.
Granville. Sci. Lab. of Denison Univ., Bul. vi, 2.
Denison Scien. Assoc., Bul. vii, 1892.
Greece. Library at Athens. Catalogue. Archeology, 1891. Report of Trustees for 1890-91.

H.

Halifax. Nova Scotian Institute of Nat. Sci. Pro. and Trans. Ser. 2, i, 1.
Hanover. Naturhistorischen. Gesell. Jahresbericht, xi, xii.

I

Iglo. Austria-Hungary. Ungarischen Karpathen-Vereins, Jahrbuch, vi, xviii.

Ungarischen Karpath-Vereines, Jarbuch xix, 1892.

Indianopolis. Stone, Vol. 5, No. 1, June, 1892.

Iowa City. Lab. of Nat. Hist. State Univ. Bulletin ii, 2,

K

Kiel. University. 114 Pamphlets, mostly inaugural dissertations.

Naturwissenschaftlichen Vereins fur Schleswig Holstein, Schriften, ix, 1891.

University. 67 Inaugural Dissertations; Die Entdeckungen auf dem Gebiete du Klassischen Philologie, 1891; Das Kaiserthune; Verzeichuiss der Varlesungen von Oct., 1891, zu March, 1892; und von April, 1892, zu August, 1892; Chronik for 1890-91; und fur 1891-92; "Guilemi ii," 27th Jan., 1892; Portraits von 22 Professoren.

Schriften Naturw. Vereins fur Schleswig-Holstein. Band ix, Heft 2, 1892.

Konigsberg. Schriften der Physik-Okonom Gesell. 32nd year, 1891.

Physikalisch-Okonomischen Gesell. Hohenschichten Karte, Sec. Kronigsberg; Sec. Danzig; Sec. Bromberg-Marienwender.

L

Leeds. Geol. Assn. Transactions, vi. 1891.

Leipzig. Vereins fur Mittheilungen, 1888; Beitrage zur Geographic des Festen Wassen, 1897.

Mitt. Vereins for Erdkunde, 1891.

Lille. Soc. Geol. du Nord. Annales xix, 1891.

Lund. University Ars-skrift xxvii, 1890-91.

Luxemburg. Verein Luxemberger. Naturfreunde. "Fauna" No. 1: 1892.

M

Madison. State Hist. Soc. proc. xxxix. 1891.

Marburg. Gesell. zur Beforderung der gesamten Naturw. Jahrgang 1891.

Mecklenburg. Archiv Vereins Freunde Naturgesch 45th year, 1891.

Mendon. American Antiquarian xii (2-6), xiv (1, 3, 4).

Mexico. Memoires y Revista della Sociedad Cientifica "Antonio Alzate" Tomo vi. Nos. 1 and 2.

Sociedad Cientifica "Antonio Alzate" Memoires y Revista iv; 11, 12; v. 1, 2, 5, 6, 9, 10.

Boletin Mensual-Observatories Meteorologico. Tomo iii. No. 4, for April 1890. Printed 1892.

Memoires y Revista Sociedad Cientifica "Antonio Alzate" Tomo v. (1891-1892) Nos. 7, 8, 11, 12. 1892.

Minneapolis. American Geologist. viii. 4-6; ix. 1-2, 4-6; x. 1-2.

Mexico. Ministerio de Fomento, Anales ix. 1891; Observatories Meteorologico Magnetico Boletin Mensual iii, 2, 3.

Metz. Vereins fur Jahresbericht xiii.

Milwaukee. Wisconsin Academy of Science. Transactions i-vi, viii.

Minneapolis. Acad. Nat. Sci. Bulletin iii, 2. 1887-89.

American Geoligist. Vol. x. Nos. 3, 4. 1892.

American Geologist. Vol. x. No. 6. Dec. 1892.

Geol. and Nat. Hist. Survey of Minn. Bulletin 7, 1892.

Minnesota Hist. Soc. Collection vi. 2. 1891; i. 1850-56; ii. 1860-67; iii. 1870-80; v. 1885; vii. 1893; and Seventh Biennial Report 1893.
Montreal. Canadian Record of Science iv. 7, 8; v. 1, 2.
Moscow. Soc. Imp. Naturalists. Buls. 1, 2, 3; 1891, iv; 1892, i.

N

New Hampshire. Geol. and Minerolog. Sur. An. Rep. I, II. 1868–70.
New Haven. New Order of Extinct Eocene Mammals (Mesodoctyla).
New York. Am. Geog. Soc. Bul. xxii with Supplement xxiii, 3, 4, Part 1; Part 2; xxiv, 1.
Notice of New Reptiles from the Laramie Formation.
Academy of Science, Transactions, x, 2–6; Annales vi, 1–4.
Minerals i, 1, Jan. 1892.
Bulletin Amer. Geog. Soc. xxiv. 2, June 1892, Trans. Academy of Sciences xi, 3, 4, 5, 1891–92; Catalogue of Microscopes, Bausch & Lomb Optical Co.; Catalogue No. 8, the Ingersoll-Sergeant Drill Company.
Bulletin Amer. Geog. Soc. vol. xxiv, No. 3. Sept. 1892.
Nurmberg. Naturhistorischen Gesell. Jahresbericht viii, 8–13.
Abh. u Jahresb. Naturh. Gesell. Band ix. 1891.

O

Ottawa. Contributions to Can. Micro-paleontology iii. 1891.
Cambro-Silurian Rocks. 1883.
Contributions to Micro-Paleontology, Canadian Geol. Survey; Pt. iv, 1892.
Case of Maps for An. Rep. Vol. iv, of Geol. Sur. of Canada.

P

Paris. Soc. Zool. de France, Bulletin xvi, 7–10; xvii, 1–5; Memoires iv, 3-5, v. 1.
Bul. Soc. Sci. Nat. de l'Ouest de la France, Tome ii, No. 2. 1892.
Mem. Soc. Zool. de France. Tome v. Pt. 4, 1892; Bul. Soc. Zool. de France Tome xvii, No. 6, 1892; Bul. Soc. Zool. de France Tome xiv. No. 6, 1889.
Mem. Soc. Zool. de France, Tome v. Parts 2 and 3. 1892.
Peoria. Flora Peoriana. The Vegetation in the Climate of Middle Ill. 1887.
Philadelphia. Acad. of Nat. Sci. Proc. Vol. xxii. Part 1. 1892.
American Naturalist xxv. 298–308, 1892.
American Naturalist xxvi, No. 309-310-311, Sept., Oct., Nov., 1892.
Prag. Konigl. Bohn. Gesell: der Wissensch. Sitzungsb. Math-Natural class 1891., Jahresb. 1891.

R

Rio Janeiro. Museu. Nacional de Rio de Janeiro. Archivos i–vi. 1876-1882.
Rochester. Academy of Science Proc. i, 2.

S

Santiago. Actes Societe Scientifique. II. 2, 1892.
San Francisco. Cal. Academy of Science Proceedings, III. 1, 1891.
San Jose. Instituto Fisico-Geographico Nacionalde Costa Rica, Annales II. 2.

San Salvador. Observaciones Meterologicos, Aug.-Dec. 1891.
Observatories Astronomico y Meterologico, Resumen, June, 1892.
Observaciones Meterologicos hecas en el Observatories. Feb. 1892.

Salem. Bulletin of Essex Institute. Vol. xxiv, No. 3, Sept. 1892.

Scranton. Tabular Estimate of the Production of Coal in Northern Anthracite Coal Basin of Penn., 1892.

Springfield. Geological Survey of Illinois. Geol. and Paleon. VIII., 1890.

St. Louis. Missouri Botan. Garden. Annual Report, 1891.
Academy of Science, vol. vi, No 2, 1892.

St. Petersburg. Comite Geologique, Memoirs, xi. 2. Bul. 9, 10; x. 1, 5 with supplement.
Bul. de Comite Geologique, vol. x, Nos. 6-10; vol. xi. Nos. 1-5, 1892.
Verhandl Russ.-Kais-Mineral. Gessellschaft, 2d series, vol. xxviii, 1892.
Memoirs du Comite Geologique. Vol. xiii, No. 1.

St. Paul. Minnesota Historical Society. Minn. Hist. Collection, vi, 1, 1887.

Stockholm. Entomologiska Foreningen Tidskrift, xii, 1-4.
Geologiska Foreningen Forhandlinger, xiii, 1-5.

Sydney. Geol. Soc. of Australasia. Special Volume of Proceedings, 1885.
The Wealth and Progress of N. S. Wales, 1889-90.
Official Report of Nat. Aust. Convention. Debates, Mar. 2-Apr. 9, 1891.
The Year Book of Australia for 1891. 10th year.

T

Toronto. Can. Institute. Trans. II, 1-4. Appeal to Can. Instit. on Rectification of Parliament.
Proc. Can. Inst., 3d Series, Vol. VII, No. 2, April, 1890.
Trans. Can. Inst. Vol. III, Part 1, No. 5, Dec. 1892.

Throndhjem. Det Kongelige Norske Videnskabers Selskabs. Skrifter, 1888-90.

U

Upsala. University. Aarsskrift. 1890.
Upsala Universitets Aarsskrift. 1891.

W

Washington. U. S. Geol. Sur. An. Rep. x, 1888-89; Bulletins 62, 65, 67-81.
Smithsonian Inst. An. Rep. 1890. Bul. Nat. Mus. 41, 42. Proc. xiv, 851, 857, 864, 865, 867-883, 858-860, 886; xv, 887, 888. Proc. for 1891, pp. 1-50.
Note on the Geuus Chonerlius or Xenopterus.
On the Genus Gnatyanacanthus of Bleeker.
Philosophical Soc. Bul. xi, 1888-91.
U. S. Nat. Museum. Spec. Bul. No. 1, 1892. Bul. 39, pts. F. and G, from Rep. U. S. N. M. 1890; pp. 253-383; 385-394; 395-409; 411-427; 429-591; 593-639; 641-680; from Proc. U. S. N. M. xv. pp. 889-894; 897-898; 900-904.
Chinese Relics in Alaska. U. S. N. M.
Description of a new species of star-gazer from Gulf of Mexico. U. S. N. M.

Description of two new forms of Basilenterus rifilfrous from Mexico. U. S. N. M.

List of Foreign Correspondents of Smith. Inst. July 1885; Additions and Corrections July, 1888. Systematic arrangement of list July, 1888.

Mineral Resources of the U. S., Geol. Survey, 1889–90.

Smithsonian Inst. Excerpts Nos. 911–914 from Proc. U. S. Nat. Museum, vol. xv. 1892,

Bulletin Philo. Soc. vol. xi, 1888–91.

Proc. U. S. Nat. Mus. Title page and contents of vol. xiv, 1891.

Wien. K.K Zoologisch-Botanischen Gesellschaft, Verhandlungen xli,31-4.

Annalen K. K. Naturb. Hofmuseums. Band vii, Nos. 1, 2. 1892.

Verhandl. K. K. Zool.-Bot. Gesell. Band xlii, Nos. 1 and 2. 1892.

Z

Zurich. Naturforschenden Gesell. Vierteljahrschrift 1891, Neujahrsblatt xciv, 1892.

Vierteljahrschrift Naturf. Gesell. in Zurich, 37th year, 1st pt. 1892.

Vierteljahrschrift Naturf. Hofmuseums. Band vii, Nos. 1, 2. 1892.

Generalregister der Publikationen der Naturf. Gesell. 1892.

INDEX.

A

B

C

N

O

P

Q

R

S

T

U

V

W

THE GEOLOGICAL

AND

NATURAL HISTORY SURVEY

OF MINNESOTA.

The Twenty-first Annual Report, for the Year 1892.

N. H. WINCHELL,

State Geologist.

MINNEAPOLIS:

HARRISON & SMITH, STATE PRINTERS.

[illegible]

THE GEOLOGICAL

AND

NATURAL HISTORY SURVEY

OF MINNESOTA.

The Twenty-first Annual Report, for the Year 1892.

N. H. WINCHELL,

State Geologist.

MINNEAPOLIS:
HARRISON & SMITH, STATE PRINTERS,
1893.

N. H. Winchell
State Geologist

THE BOARD OF REGENTS

OF THE

UNIVERSITY OF MINNESOTA.

Hon. Greenleaf Clark, St. Paul,	1898
Hon. Cushman K. Davis, St. Paul,	1898
Hon. John S. Pillsbury, Minneapolis,	1896
Hon. John Lind, New Ulm,	1896
Hon. Joel P. Heatwole, Northfield,	1897
Hon. Stephen Mahoney, Minneapolis,	1895
Hon. Sloan M. Emery, Lake City,	1895
Hon. Ozora P. Stearns, Duluth,	1897
Hon. William Liggett, Benson,	1897
Hon. Knute Nelson. Governor of the State	*Ex officio.*
Hon. D. L. Kiehle, Superintendent of Public Instruction,	*Ex officio.*
Dr. Cyrus Northrop, President of the University,	*Ex officio.*

OFFICERS OF THE BOARD.

Hon. J. S. Pillsbury,	*President.*
Hon. D. L. Kiehle,	*Recording Secretary.*
Pres. Cyrus Northrop,	*Corresponding Secretary.*
Hon. O. C. Merriman,	*Treasurer.*

ADDRESS.

MINNEAPOLIS, MINN., Oct. 20, 1893.

To the President of the Board of Regents:

DEAR SIR.—The twenty-first annual report of the Geological and Natural History Survey of the state is herewith submitted. It embraces statements relating to progress in the strictly geological portion of this enterprise, and to the General Museum and the library accessions. The botanical and zoological departments of this work have been placed, by the Board of Regents, under the personal direction respectively of Prof. Conway MacMillan and Prof. Henry F. Nachtrieb, and they will make independent reports directly to the regents.

Respectfully submitted,

N. H. WINCHELL,

State Geologist and Curator of the General Museum.

CONTENTS.

I.

SUMMARY STATEMENT AND COMPARATIVE NOMENCLATURE.

In the season of 1892 the field work of the survey was continued in the northeastern part of the state, where the economic development of the new iron range (the Mesabi) continued unabated. Considerable time was spent on the central and western portions of the Mesabi range, with a view to learn the geological relations of the ore bodies. By this time, as shown in the report of H. V. Winchell published in the last annual report, some general idea had been gained of the position and forms of these ore deposits, warranting an attempt at a more systematic description, which should serve at least for many practical purposes and as a preliminary statement of many of the geological environments. At the same time this early reconnoissance brought to light many new facts and features, the full elucidation and publication of which will require careful chemical and petrographical research, and a comparison with the similar features of the iron ranges of adjoining states.

Dr. U. S. Grant continued an examination, which he had begun, of a granitic area near the eastern extension of the Mesabi range, viz: that about Kekequabic lake, and extended his field studies, with careful detail, to the eastern end of Otter Track lake, and southward to and beyond Little Saganaga lake. Later he spent much time on the eastern end of the Mesabi range proper, westward from Gunflint lake, examining the relations of the gabbro and the magnetites to the Pewabic quartzyte.

Simultaneously with this the writer extended his field work over a region not before visited by him, including Snowbank lake and the region between it and the Kawishiwi river, and subsequently with Dr. Grant reviewed some of the important portions of the region of Kekequabic and Ogishke Muncie lakes.

In May a reconnoissance was made by the writer, accompa-

nied by Messrs. Grant and Schuchert, of the region about Potsdam, N. Y., with the view to obtaining, if possible, some data for the settlement of some of the pending questions respecting the stratigraphic position of the true Potsdam sandstone. This trip was continued to Keeseville, N. Y., on the east, and to Gouverneur, N. Y., on the west.

Mr. E. O. Ulrich spent a year at Minneapolis, and much progress was made on the paleontology of the Trenton and Hudson River formations, the results being incorporated in volume III of the final report, still in press. Of this volume several chapters have already been issued separately, viz:

Chapter I. Cretaceous fossil plants from Minnesota. By *Leo Lesquereux*, pp. 1-22, 2 plates. Published Feb. 15, 1893.

Chapter II. Microscopical fauna of the Cretaceous in Minnesota, with additions from Nebraska and Illinois. By *Anthony Woodward* and *Benjamin W. Thomas*, pp. 23-54, 3 plates. Published Feb. 15, 1893.

Chapter III. Sponges, Graptolites and Corals, from the Lower Silurian of Minnesota. By *N. H. Winchell* and *Charles Schuchert*, pp. 55-95, 2 plates. Published June 6, 1893.

Chapter IV. On Lower Silurian Bryozoa of Minnesota. By. *E. O. Ulrich*, pp. 96-332, 28 plates. Published Jan. 15, 1893.

Chapter V. The Lower Silurian Brachiopoda of Minnesota. By *N. H. Winchell* and *Charles Schuchert*, pp. 333-474, 6 plates. Published June 6, 1893.

During the year also the twentieth annual report has been published, and Bulletin VII, devoted to the mammals of the state, by Prof. C. L. Herrick, has been issued from the press and distributed. The work of Dr. P. L. Hatch, on the Birds of Minnesota, has been published through the zoological department of the survey, under the supervision of Prof. H. F. Nachtrieb.

The following papers relating to the geology of the state have also been published elsewhere by members of the Geological Survey corps, viz:

The geology of Hennepin county. *N. H. Winchell.* (In the "History of Minneapolis", by *I. Atwater.*)

An approximate interglacial chronometer. *N. H. Winchell.* American Geologist, vol. x, p. 69, August, 1892.

Preliminary descriptions of new Brachiopoda from the Trenton and Hudson River groups of Minnesota. *N. H. Winchell* and *Charles Schuchert.* American Geologist, vol. ix, p. 284, May, 1892. (Advance copies were distributed to American paleontologists, April 1, 1892.)

The Kawishiwin agglomerate at Ely, Minn. *N. H. Winchell.* American Geologist, vol. ix. p. 359, June, 1892.

Some problems of the Mesabi iron ore. *N. H. Winchell.* American Geologist, vol. x, p. 169, September, 1892.

Frondescent hematite. *N. H. Winchell*, American Geologist, vol. xi, p. 20, January, 1893.

The geology of the iron ores of Minnesota. *N. H. Winchell*. Trans. Geol. Soc. Australasia, Melbourne, vol. 1, pp. 171–194, 1892.

The stratigraphic position of the Ogishke conglomerate of northeastern Minnesota. *U. S. Grant*. American Geologist, vol. x, p. 5, July, 1892.

Note on an augite sode-granite from Minnesota. *U. S. Grant*. American Geologist, vol xi, p. 383, June, 1893.

New Lower Silurian Ostracoda. *E. O. Ulrich*. American Geologist, vol. x, p. 263, Nov., 1892.

Two new Lower Silurian species of Lichas (subgenus Hoplolichas). *E. O. Ulrich*. American Geologist, vol. x, p. 271, Nov., 1892.

Classification of theories of the origin of iron ores. *H. V. Winchell*. American Geologist, vol. x, p. 277, Nov., 1892.

A classification of the Brachiopoda. *Charles Schuchert*. Am. Geol., vol. xi p. 141, March, 1893.

New Lamellibranchiata. *E. O. Ulrich*. Am. Geol., vol. x, p. 96, August, 1892.

Mesabi developments. *H. V. Winchell*. Iron Trade Review, Cleveland, April 19, 1892.

Cost of mining on the Mesabi. *H. V. Winchell*. Iron Trade Review, Cleveland, July 21, 1892.

Is there a shortage of bessemer ore? *Anon*. (*H. V. Winchell*). Iron Trade Review, Cleveland, Feb. 16, 1893.

The Mesabi iron range. *H. V. Winchell*. American Institute of Mining Engineers, Schuylkill Meeting, vol. xxi, pp. 644–686, Oct., 1892.

The Biwabik mine. *H. V. Winchell* (with *John T. Jones*). Am. Inst. Min Engineers, Montreal Meeting, vol. xxi, pp. 951-961, Feb., 1893.

Minnesota iron mines. *Anon*. (*H. V. Winchell*). Published in "Minnesota, a brief sketch of its History, Resources and Advantages," by authority of the State Board of World's Fair Managers, pp. 119–123, Pioneer Press, St. Paul, 1893.

Prof. J. E. Todd, of Vermillion, S. Dak., was engaged to complete the survey in the northwestern portion of the state, extending from the Red river valley eastward to the east side of Beltrami county, and he has spent the months of July and August in that region. His accompanying preliminary report shows in outline the progress he has made. It will require another similar season's campaign to clear up sufficiently for report the geological features presented in that area.

The work of the year has been very largely paleontological. Some re-examinations were made by Messrs. Schuchert and Ulrich, under the guidance of Mr. Scofield, of the fossiliferous Lower Silurian outcrops in the southeastern part of the state, with the view to determine more exactly the stratigraphic range of the fossils belonging to the survey collection, and for the purpose of further collection at the same points.

COMPARATIVE NOMENCLATURE.

The former annual reports of the Minnesota survey have presented, occasionally, short discussions and tabulations of the Pre-Silurian rocks of Minnesota, embracing different portions of the series. These have also sometimes contained references to their supposed parallels in other parts of the Northwest. Owing to occasional misapprehensions by other geologists of the stratigraphy of these rocks, as we have made it out, and the misuse of some of our terms, an attempt has been made to place the Minnesota strata in proper order in the adjoined table. This table also expresses the stratigraphy of the Wisconsin reports, issued under the direction of Prof. Chamberlin, the terms used by the present Michigan survey and the general terms used by the United States and Canadian geological surveys. The table has had the approval of Messrs. Wadsworth, Van Hise and Selwyn, for their respective portions.

II.

THE GEOLOGY OF

KEKEQUABIC LAKE

In Northeastern Minnesota

WITH SPECIAL REFERENCE TO

An Augite Soda-Granite

BY ULYSSES SHERMAN GRANT

A THESIS ACCEPTED FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN THE JOHNS HOPKINS UNIVERSITY, JUNE, 1893.

CONTENTS.

ILLUSTRATIONS.

PREFACE.

In this paper an attempt is made to present a description of the geology of a small part of the complex area of northeastern Minnesota in more detail than has been done hitherto. In order to give a connected account of the geology of this area it has been necessary to duplicate in small measure some of the former descriptions; this is true of part of the descriptions of some of the clastic rocks, the argillytes, graywackes and conglomerate. But some of the earlier accounts have been enlarged somewhat, and to the whole has been added a number of petrographical descriptions. The points of special interest in this paper, which have not been presented previously, are: (1) Petrographical description of the anomalous green schists. (2) Notice of a small area of hornblende porphyrite. (3) Investigation of the petrography of the granite, which is shown to be of a rather uncommon and interesting type—*an augite soda granite.* (4) Evidence is brought forward to show that the granite is of truly eruptive origin and that it is not a recrystallized condition of the sediments of the region *in situ*, as it has been considered in most of the previous papers on this region.

All of the field work and part of the laboratory work for the preparation of this article was done while the writer was in the employ of the Geological and Natural History Survey of Minnesota. During the summer of 1891, while studying several granite areas in northeastern Minnesota, several days were devoted to the granite of Kekequabic lake, and again, in the summer of 1892, more time was employed in studying the rocks around this lake. Thanks are due to Prof. N. H. Winchell, State Geologist of Minnesota, for assistance and advice during the prosecution of this work, and for his kindness in allowing part of the investigation to be carried on outside of laboratories of the Survey.

The writer also desires to express his sincere thanks to Prof. George H. Williams of the Johns Hopkins University for kindly aid and numerous suggestions from the beginning to the end of this investigation. To him is due in large measure whatever of merit this paper may possess.

The analyses were made by Profs. J. A. Dodge and C. F. Sidener of the University of Minnesota.

CHAPTER I.

GENERAL DESCRIPTION OF THE AREA STUDIED.

LOCATION.

The area described in this paper is a small portion of the triangle in Minnesota which lies between lake Superior and the Canadian boundary. This part of the state is made up of more or less highly crystalline rocks of pre-Cambrian age. The region described is about the centre of the northern side of this triangle. Kekequabic lake, the geology of whose shores is here presented, lies in the northeastern part of Lake county, in latitude 48° 2′ north and longitude 91° 6′ west of Greenwich. It is less than two miles south of Knife lake, which is one of the narrow bodies of water forming the boundary between Minnesota and Ontario.

The exact position of Kekequabic lake can be seen on Plate XLI, "Geological map of northeastern Minnesota," of Irving's paper "On the classification of the early Cambrian and pre-Cambrian formations."* A larger and more accurate map of the region is that included in the "Fifteenth (1886) Annual Report of the Geological and Natural History Survey of Minnesota"; and a still better one is that found in "The iron ores of Minnesota."†

The accompanying sketch map (Fig. 1) shows the western part of the lake Superior basin and the adjacent territory. A glance at this map will give a general idea as to the location of the region to be described in this paper. The star shows the approximate position of Kekequabic lake.

An area extending five miles in an east and west direction and about the same distance north and south is represented in the geological map (Plate II) and is the area described. It con-

*U. S. Geological Survey, 7th Ann. Rept, pp. 365–454, 1888.

†Geol. and Nat. Hist. Survey of Minn., Bull. No. 6, 1891.

tains sections 29, 30. 31 and 32 of township 65 N., range 6 W. of the 4th Principal meridian; sections 25, 26, 27, 34, 35 and 36 of T.65 N., R. 7 W.; sections 5, 6, 7 and 8 of T. 64 N., R. 6 W.; and sections 1, 2, 3, 10, 11, 12 and the east half of section 4 of T. 64 N., R. 7 W.

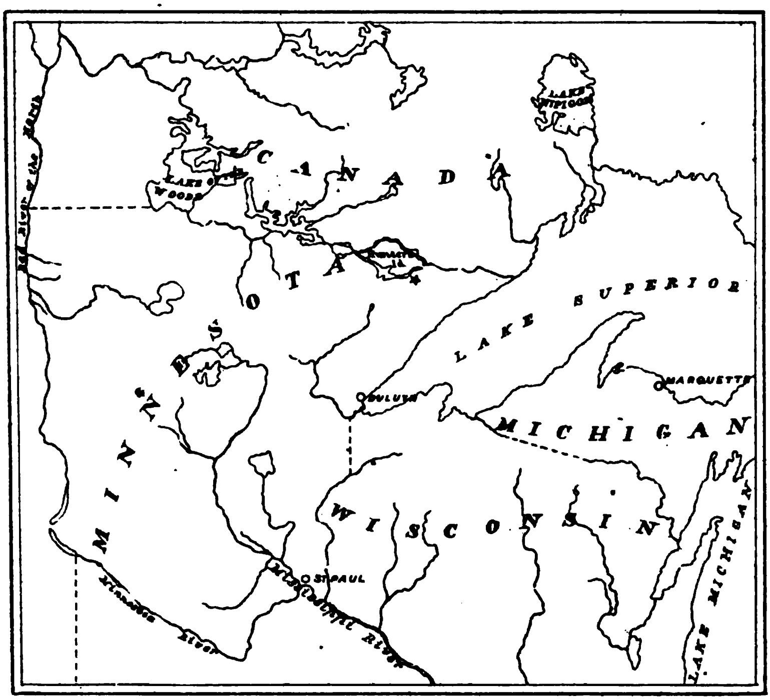


FIG. 1. Sketch map of the western end of lake Superior and adjacent territory showing the location of Kekequabic lake.

TOPOGRAPHY.

The surface is rough and hilly, though not strictly mountainous. The elevations consist of more or less broken parallel hill ranges, which trend a little north of east. The most important of these ridges lies along the south side of Kekequabic lake. In the southwest quarter of section 36, T. 65 N., R. 7 W., this range attains a hight of 240 feet above the lake level; farther east,—in the S. E. ¼ section 31, T. 65 N., R. 6 W., —it rises over a hundred feet higher, and two miles farther east, just outside the area of the map, are the twin peaks which are more than 500 feet above the lake or 2,000 feet above sea level. These peaks are visible for many miles in any direc-

tion and form the highest land in the northern part of Lake county. Kekequabic lake, as ascertained by level, is 1,498 feet above the sea. On the north shore of the lake is another noticeable ridge attaining an elevation of 260 feet in the N. E. ¼ section 35, T. 65 N., R. 7 W. Mallmann's peak is a continuation of the same ridge in the S. E. ¼ section 30, T. 65 N., R. 7 W.; its summit is some 250 feet above the lake, its southeastern front rising in an almost vertical precipice for 200 feet. The two hill ranges above mentioned are by far the most conspicuous in the area under consideration, but lower elevations of gentler slope are common. The western shores of the lake are comparatively low, and oftentimes the land is swampy for a considerable distance from the water's edge.

By far the larger part of the land surface is rough and hilly. The hills are almost entirely of rock, there being no drift ridges, but some of the elevations have parts of their surfaces covered by a thin mantle of glacial material. Between the hills lie lakes, which constitute about a third of the surface. There are also some low areas, which are swampy, but these are of considerably less extent than the lakes. The surface may be roughly divided into three parts,—hills, lakes and swamps,—in the relative proportions of 3, 2 and 1.

Very noticeable features of the topography are the precipitous cliffs, which rise vertically from the water's edge to the hight of from 10 to 200 feet. The highest of these, Mallmann's peak, has already been mentioned. Others occur on the north and south sides of Stacy island and along the south shore of the lake a short distance east of this island. These cliffs, as a rule, face toward the north or the south and they lie parallel with the hill ranges and the long axes of the lakes. It is quite probable that the cliffs occur along lines of faulting.

LAKES AND DRAINAGE.

The lakes of this region lie in rock bound basins, and a large number of them are elongated in a direction parallel with the hill ranges. From one rocky basin a short, rapid stream carries the water down to the next lower basin; in this way the greater part of the drainage is accomplished. These streams, connecting one lake basin with another, often have a considerable fall in a short distance; for instance the outlet of Epsilon lake, through which the waters from Kekequabic lake flow, descends 80 feet in a distance of about 100 yards. One of the cascades of this stream is shown in Plate I, Fig. 1.

Kekequabic lake, the largest in the area studied, is clear and deep. It is a narrow body of water, some five miles in length; its eastern half never reaches a width of more than half a mile, while its western part is broader, being nearly a mile and a half wide. To the north of Kekequabic lake lie several smaller lakes, more shallow and not surrounded by as noticeable hills.

The streams of the region, excepting those connecting one lake with another, are small and insignificant. They have cut no appreciable channels of their own and have carried very little sediment into the lakes. In no place has a stream begun to build a delta at its mouth. Since the lakes serve as resting places for what little sediment is brought down by these streams, the larger streams flowing from one lake to another are practically free from suspended material and so have little eroding power, even though they are often very rapid. Thus the surface is suffering comparatively little denudation and presents now almost the same contours and depressions which existed when the ice sheet departed. Then, as now, there were hills and deep valleys filled to their edges with water, and since then these lakes have been lowered very little by the wearing down of their outlets. The whole drainage follows the depressions left by the ice sheet and is not dependent on the character of the underlying material, be it drift or crystalline rock. The drainage of the Kekequabic basin is toward the north, through several small lakes lying north of the east end of this lake, to Knife lake,—one of the series of International Boundary lakes belonging to the Rainy Lake system.

SOIL AND FOREST.

The land surface is covered by but a thin layer of soil. This consists in places of glacial material, but where drift deposits are lacking a layer of soil of only a few inches thickness has accumulated. This scanty soil is entirely sufficient, even when but three inches deep, to support a luxuriant forest of conifers;—in fact the surface is usually covered by a thick growth of black pine (*Pinus banksiana* Lambert), red pine (*P. resinosa* Ait.) white pine (*P. strobus L.*), balsam fir (*Abies balsamea* Marshall), black spruce (*Picea nigra* Link.) and arbor vitæ (*Thuya occidentalis L.*); the last two are confined mostly to the lower ground. Considerable areas of the forest were burnt some years ago and these areas are now covered with a thick and tangled second growth, in which the white birch (*Betula*

papyrifera Marsh) and aspen (*Populus tremuloides* Michx.) play an important part. This dense growth, coupled with thickly strewn fallen logs, renders exploration of such areas unusually difficult.

ROCK EXPOSURES.

Around the lake shores there are rather frequent exposures. The outcrops vary greatly in size, and their frequency and extent do not seem to be conditioned by the character of the rock, the softest and most easily eroded often extending for considerable distances along the lake shore; this is especially noticeable in the case of the soft, fissile, green schist, which is seen in such large development along the north side of the central part of the lake. However, there are stretches of shore a quarter of a mile or more in length where no rock is to be seen *in situ*; this is generally true along the low and swampy shores and in a few other places where there are larger accumulations of drift than is usual. In some cases, as before mentioned, almost vertical cliffs rise directly from the water's edge from 10 to 200 feet above the lake surface. Along these cliffs and elsewhere on the steeper hillsides numerous and extensive exposures are accessible. Along the streams there are fewer outcrops than would be expected, for the streams usually flow in depressions more or less filled with glacial material and they have as yet but infrequently cut down to the underlying rock; in fact their channels are generally boulder filled, and, contrary to a geologist's expectation, he can find little clue to the underlying rocks by following up these stream beds. Many of the hills, especially those of gentle slope, show no outcrops, and it is only on their summits and steep sides that one finds many large exposures away from the actual lake shore. The comparative thinness of the drift and its almost total absence over areas of some extent would seem favorable to the existence of more extensive exposures than are to be found. But in many cases where the drift is almost absent vegetation has gained a foothold, and at present the rock is covered with soil, moss, rock-fragments and decaying sticks and logs, the whole forming a layer two inches to two feet in thickness, firmly bound together by numerous roots, so that with the aid of merely a hammer the subjacent rock is as inaccessible as when buried under several feet of drift.

The weathered and decayed rock of the whole region has been almost completely carried away by glacial action; and

since the departure of the ice there has been but little surface decay, such as there is extending but a fraction of an inch below the surface. Thus the exposures, with few exceptions, furnish clean and unweathered specimens. The only rock which shows evidence of post-glacial decay and alteration is the green schist, and this is decaying in but a few places, the most noteworthy being on the extreme western side of the promontory from the north side of the lake, at the northeast corner of section 31, T. 65 N., R. 6 W. From this it is not to be supposed that the rocks are in a perfectly unaltered state, for their minerals have been more or less affected by destructive processes, other than mere surface weathering, acting through long geological ages, but the rocks are now in practically the same condition as at the end of the Glacial period.

OUTLINE OF GEOLOGICAL FEATURES.

The northern edge of Lake county, where Kekequabic lake is situated, is composed entirely of pre-Cambrian rocks, which have suffered more or less metamorphism. Leaving out of consideration their exact stratigraphical positions and designations, we shall proceed to a very brief description of the various rock types. The discussion as to the nomenclature, precise age and relationships of the various formations is reserved for another part of this paper.

By far the larger proportion of the rock masses represented in this area are sedimentary in character, but some of the material is of volcanic origin and some of this was probably deposited in water. These sediments may be divided for convenience into four groups, although this division is arbitrary to some extent, as the different groups are not always sharply separated from one another. The first and by far the most widely developed group is that which may be termed the slate formation. This consists largely of argillytes, with smaller amounts of fine and coarse graywackes and grits. The argillytes, graywackes and grits are closely associated with each other, being oftentimes intimately interbanded, so that it is impossible to map them separately. The coarser facies of the rocks just mentioned often become distinctly conglomeratic in small areas, and in other places there are conglomerates which are composed of very coarse boulders;—these conglomeratic rocks form the second group. The third group is made up of certain peculiar, fissile, green schists, which have usually been

called chloritic schists. While the fourth group is composed of more or less marked fragmental volcanic material, which in places shows a banding apparently due to deposition in water. These clastic rocks have been greatly disturbed since their deposition, and they now stand in nearly vertical positions with a strike that is a little north of east.

Sharply marked off from the clastics are four types of igneous rocks, whose age, with perhaps the exception of the first, is later than that of the surrounding clastics. The first of these igneous rocks is a peculiar, purple, hornblende porphyry, more precisely a hornblende porphyryte. The other rocks of igneous origin are granite, diabase and gabbro. The first is divisable into two types,—the ordinary granite and a granite porphyry, the latter of which is seen only in small patches. These two types of granite are of interest from the fact that their ferro-magnesian constituent is almost exclusively pyroxene and that the predominating feldspar is anorthoclase. The diabase is found only in a few small dykes cutting all the other rocks, excepting possibly the gabbro. Unconformably above all the other rock series is a coarse grained gabbro. The country shows no remains of any strata younger than the gabbro, which is of Keweenawan age, and older than the drift.

PREVIOUS LITERATURE.

The descriptions of the rocks of Kekequabic lake are to be found almost wholly in the reports of the Geological and Natural History Survey of Minnesota, and a list of references to this locality is here appended (I). Under each reference are a few words briefly explaining the character of the descriptions; the articles are given in order of date of publication. Following this list is another (II) giving the titles of the more important papers which relate to the rocks of northeastern Minnesota that occur at Kekequabic lake; this second list makes no pretensions to completeness.

I. *Articles relating to Kekequabic Lake.**

1882.—N. H. Winchell. 10th (1881) Ann. Rept., pp. 92–93.
A single specimen (No. 751) of peculiar porphyry (hornblende porphyryte) is reported from Mallmann's peak.

*All the articles in this list, excepting the last, are to be found in the publications of the Geological and Natural History Survey of Minnesota.

1887.—M. E. Wadsworth. Bull. No. 2, Preliminary description of the peridotytes, gabbros, diabases and andesytes of Minnesota, pp. 124-125. A microscopical description of the above mentioned specimen of hornblende porphyryte is given and sections of it are figured (Pl. X, Figs. 1 and 2).

1887.—A. Winchell. 15th (1886) Ann. Rept, pp. 148-156.
Detailed field descriptions confined mostly to the south shore of the lake.

1887.—N. H. Winchell. 15th (1886) Ann. Rept., pp. 361-369.
Field notes on the rocks of the lake shore. Special attention is given to the structure and origin of the gneiss (granite) and porphyry (granite porphyry).

1888.—N. H. Winchell. 16th (1887) Ann. Rept., pp. 100-108.
A continuation of the last report with some general statements concerning the genesis and relationships of the various rock-series.

1888.—A. Winchell. 16th (1887) Ann. Rept., pp. 321-327.
Field notes about Epsilon lake. An unconformity is noticed between the Animikie and Keewatin and mention is made of several exposures of purple porphyry (hornblende porphyryte).

1893.—U. S. Grant. 20th (1891) Ann. Rept., pp. 69-82.
Field notes on the region about Kekequabic lake, with special reference to the granite. It is stated that the gneiss of the former reports is a fine grained pyroxene granite and that the porphyry is a pyroxene granite porphyry.

1893.—U. S. Grant. Note on an augite soda-granite from Minnesota; Amer. Geologist, vol xi, No. 6, pp. 383-388.
A preliminary petrographical description of the granite of Kekequabic lake is given. It is shown that the rock is an augite soda-granite with a large percentage of soda, which finds expression in the composition of the augite as well as in that of the feldspar.

II. *Articles on northeastern Minnesota and adjacent territory.*

N. H. Winchell.—Geol. and Nat. Hist. Survey of Minn., 7th (1878) Ann. Rept., 1879.—9th (1880) Ann. Rept., 1881.—10th (1881) Ann. Rept., 1882.—11th (1882) Ann. Rept., 1883.—13th (1884) Ann. Rept., 1885.—15th (1886) Ann. Rept., 1887.—16th (1887) Ann. Rept., 1888.—17th (1888) Ann. Rept., 1889.—20th (1891) Ann. Rept., 1893.
The Norian of the Northwest; Geol. and Nat. Hist. Survey of Minn., Bull. No. 2, pp. iii-xxxiv, 1893.

R. D. Irving—The copper-bearing rocks of Lake Superior; U. S. Geol. Survey, Mon. vol. 5, 1884.
Preliminary paper on the investigation of the Archæan formations of the northwestern states; U. S. Geol. Survey, 5th Ann. Rept., pp. 175-242, 1885.
On the classification of the early Cambrian and pre-Cambrian formations; U. S. Geol. Survey, 7th Ann. Rept., pp. 368-454, 1888.

A. C. Lawson.—Report on the geology of the Lake of the Woods region, with special reference to the Keewatin (Huronian?) belt of Archæan rocks; Geol. and Nat. Hist. Survey of Canada, new series, vol.

1, pt. CC, 1885. Report on the geology of the Rainy Lake region; Geol. and Nat. Hist. Survey of Canada, Ann. Rept. 1887, vol. iii, pt. F, 1889.

A. Winchell.—Geol. and Nat. Hist. Survey of Minn., 15th (1886) Ann. Rept., pp. 7-207, 1887.—16th (1887) Ann. Rept., pp. 131-391, 1888. Conglomerates enclosed in gneissic terranes; Amer. Geologist, vol. 3, pp. 153-165, 256-262, 1889.

H. V. Winchell.—Geol. and Nat. Hist. Survey of Minn., 15th, (1886) Ann. Rept., pp. 401-417, 1887.—16th (1887) Ann. Rept., pp. 393-463, 1888. —17th (1888) Ann. Rept., pp. 75-145, 1889.

N. H. and H. V. Winchell.—The iron ores of Minnesota; Geol. and Nat. Hist. Survey of Minn., Bull. No. 6, 1891.

C. R. Van Hise.—An attempt to harmonize some apparently conflicting views of Lake Superior stratigraphy; Amer. Jour. Sci., 3, vol. xli, pp. 117-137, Feb., 1891.

CHAPTER II.

THE ROCK FORMATIONS REPRESENTED.

In this chapter the different rock formations occurring in the area studied are considered in succession, but two of them—the granite and the porphyryte—are reserved for a more detailed treatment in the following chapters. In the first place the different formations, already briefly mentioned in an "Outline of geological features" in Chapter I, are to be considered lithologically and structurally. These will be taken up in the order of their supposed ages, and the discussions as to their comparative ages and relationships are brought together at the end of this chapter. It is fair to state at the outset that the following division of the clastic rocks is partly for convenience in description, and is not wholly due to the fact that they can all be distinctly separated from each other in the field or in hand specimens. Nevertheless, it is possible to recognize more or less distinctly the following rock types:—argillyte, graywacke, grit, conglomerate, green schist and volcanic tuff. The first three are often so intimately interbedded that it is impossible to separate them in mapping and general description; consequently they are grouped together and form what is termed the slate formation. The other types are more easily separated from each other and from the slate formation, and they have therefore each been mapped separately; but the boundaries shown on the geological map (Plate II) are of only approximate correctness for this reason: these rock types often seem to pass by insensible transitions into one another and each occcurs in small amounts interbanded with the others so that separation is not possible. However, there are certain areas where one type covers a large proportion of the surface and such areas have been mapped as though composed of that type. The conglomerates have been included in the rocks to which the above remarks apply, although there is a possibility that the coarse conglomerate is of a later age than the surrounding clastics; this question will be considered in another place.

THE ANCIENT CLASTIC ROCKS.

These form the country rocks of the region; geographically they cover perhaps three fourths of its area. The different parts of this series,—the slate formation, the green schist, the tuff and the conglomerate,—are more or less closely related and have many characters in common.

The strike, with some local exceptions, varies from N. 40° E. to N. 75° E., the average being about N. 60° to 65° E., which is the usual strike of similar rocks in this part of the state. The dip varies a few degrees either side of the vertical, but rarely becomes lower than 70°. This general strike and dip are practically constant over the whole area. There is, however, one noticeable exception to the general strike of the rocks of this region; this is in the west half of section 6, T. 64 N., R. 6 W., where for a considerable distance the strike is almost exactly north and south, the dip being about vertical.

The clastic rocks have been subjected to considerable dynamic action and as a result all except the coarse conglomerate have acquired slaty and schistose structures in many places. This is especially true of the argillytes and green schists, but in most cases where undoubted stratification appears it is practically coincident with the slaty or schistose structure. There are however many outcrops which show one of these secondary structures without exhibiting any distinct lines of sedimentation. And in this connection it should be stated that evidences of sedimentation are lacking over exposures of considerable size; this is especially the case in the conglomerates, tuffs, graywackes and grits, but is also true to a less extent in the argillytes. All of the clastic rocks, excepting the green schists and argillytes, are often seen possessing no evidence either of sedimentary lamination nor of secondary parallel structures; in such cases the graywackes frequently present the appearance of fine-grained massive rocks.

The slate formation.

The larger part of the area described is composed of rocks belonging to this formation. It includes almost all the northern half of the region mapped,—in fact the whole portion of the area north of Kekequabic lake, except small areas of green schist, tuff and hornblende porphyryte, is made up of rocks belonging to this formation. It also occupies the eastern side

and all of the southeastern quarter of the map, but does not occur in the southwestern quarter. These rocks reach a greater development outside of the immediate vicinity of Kekequabic lake and form a large proportion of the Keewatin rocks in Minnesota.

Lithologically the slate formation is divisible into three parts:—argillyte, graywacke and grit. The first covers some areas almost exclusively, but the others, while found in large amount, are never entirely free from bands of argillyte. Still there are certain portions of the surface where grit or graywacke is developed to almost the complete exclusion of the argillytes. These three types of rocks are found grading into each other. This is especially noticeable in the case of the graywackes and argillytes, the finer grained slaty facies of the former passing by indistinguishable steps into gray argillytes. In mapping it is of course impossible to separate areas of argillyte from those of grit or graywacke as they are so intimately interbedded, but under the description of each is given its distribution in areas where the two others are largely absent.

Argillyte.—The larger part of the region north of Kekequabic lake and also a considerable part of section 6, T. 64 N., R. 6 W. is occupied by argillytes. They are found in their best development, comparatively free from bands of grit and graywacke, just to the west and northwest of Kekequabic lake and around the shores of Epsilon lake. In color the argillytes are generally rather dark, nearly black or dark gray, but they often vary towards greenish and lighter gray tints and in one place near the corner of the bay, in which is Stacy island, to a reddish shade. Evidences of stratification are quite generally present, being shown by alternating bands of lighter and darker shades, these bands usually being from one quarter of an inch to an inch in width. Rarely there are seen areas of the darker slates where sedimentary lines are obscure or entirely lacking. The darker varieties show the best developed slaty cleavage, but in no place is this continuous and perfect enough to make the beds of economic importance.

The argillytes vary in composition in two general directions. First, by the addition of more and more silicious matter, they grade into silicious schists; variation in this direction is marked by a change in color to lighter and lighter gray. When the silica becomes more abundant and is in distinct grains the rock is approaching the graywackes and grits. Variation in the second direction is due to the addition of a chloritic or horn-

blendic (actinolite?) constituent often accompanied by an increase of silica; the rock thus assumes a greenish color and a less cleavable character. Such green slates are tough and very hard. In one place near the southeast end of Pickle lake there are narrow bands of red and black jaspilyte interbedded with these green slates. These jaspilyte bands are the nearest approach to iron ore in the immediate vicinity of Kekequabic lake. Another direction of change for the argillytes is toward sericitic schists; this variation is not seen commonly at Kekequabic lake, but is shown to some extent.

Graywacke.—This rock occurs in its best development around the east end of Kekequabic lake. It is seen in especially fine exposures in the S. W. ¼ section 29, T. 65 N., R. 6 W. It varies in grain from quite coarse graywacke, with quartz grains $\frac{1}{16}$ to $\frac{1}{8}$ inch in diameter, to a very fine gray slate. The coarser facies occur in massive beds from a few inches to many feet in thickness, and often show no parallel structures, either original or induced. Since this rock has been fully described in the reports on northeastern Minnesota it seems preferable to give a few quotations from the published descriptions of Dr. Alexander Winchell than to attempt any new description.

"The best characterized graywackes are obscurely bedded, dark gray and composed of fine grains of quartz and feldspar mostly but not exclusively monoclinic, all imbedded in a sparse or copious groundmass of a silico-argillaceous character. Disseminated through the rock are generally some black specks of an anthracitic character. Peroxide of iron also, is often present. From the condition thus described the variations are very marked. Often through an excess of quartz and a high silicification of the groundmass, the rock becomes impure-flinty, and under the influence exerted by heat, has acquired a ringing hardness, accompanied by two or three sets of jointage planes, which divide the mass into cuneiform portions. It thus seems to answer the description of *hornfels*. This condition is approximated very frequently. But, far from being persistent, we often see it pass rapidly into a well bedded terrane. In another direction, the feldspathic constituent exists in increased quantity, and the dark aspect of the other ingredients gives the rock a diabasic look, especially when, as is mostly the case, all bedded structure is completely disguised. At times it is almost impossible to decide macroscopically whether the rock is a real diabase, an anamesitic doleryte, or only an altered and aberrant graywacke."*

*Geol. and Nat. Hist. Survey of Minn., 16th (1887) Ann. Rept., p. 339, 1888.

"A very conspicuous feature of the schist belt is the frequent and abrupt transition from a pronounced slaty structure to a massive structure, in which the bedding planes are obscure, and in many cases scarcely discoverable. These massive conditions present the ordinary external appearance of diabase, and sometimes of dolerite; and it requires many observations to convince one's self that none of these are truly eruptive. At times these masses are cut by joints into cuneiform cuboids, ringing and flinty, precisely like rocks of eruptive origin; and if one were to restrict his observations to a few such occurrences, he would feel persuaded that large portions of the region are occupied by true dykes of enormous extent. But with surprising abruptness these rock-masses are seen assuming a more earthy character and losing their eruptive features. Close by, the lines of an ancient stratification come into view, and these always conform to the rule of the region. The rock may now be seen more distinctly to contain an important quartzose constituent. This is sometimes in fine, almost indefinite grains and sometimes a silicious groundmass. A different condition of the rock contains, with more or less quartz, a considerable feldspar—mostly orthoclase, but partly triclinic. This appears sometimes in distinguishable grains imbedded in the silicious or silico-argillaceous groundmass, and sometimes as a feldspathic groundmass holding obscure grains of quartz. Not unfrequently the groundmass appears to be a real petrosilex. In all cases the rock possesses great hardness and toughness. These are the macroscopic characters of a range of rocks which I have called graywacke."*

Grit.—This name is applied to a part of the slate formation which makes up the north side of the high hill in the S. E. ¼ section 31, T. 65 N., R. 6 W. The rock called grit is very intimately interbanded with fine bands of argillyte. The beds of grit vary from a fraction of an inch to fifty feet in width, and, aside from the interbanding of the argillite, show no sedimentary lamination or slaty cleavage.

This rock seems to be somewhat different from anything that has been described in the Minnesota reports; it was mentioned by the writer in one place,† but no special description was given. It is a dark gray to black rather fine grained rock showing numerous macroscopic glistening quartz grains and a few feldspar grains imbedded in a dark ground mass. The

*Ibid., 15th (1886) Ann. Rept., pp. 173-174, 1887.

†Ibid., 20th (1891) Ann. Rept., p. 79, 1893.

grains of quartz and feldspar and rock fragments (to be mentioned below) are usually from one-half to two milimeters in diameter,—often smaller and rarely larger. Under the microscope the rock is seen to be composed of sub-angular fragments of quartz and feldspar imbedded in a groundmass, which is made up almost entirely of green hornblende. The hornblende occurs in fibers and irregular grains. The fibers often are of minute size and penetrate the rock mass in all directions; they even seem to extend for short distances into certain quartz grains. Small fragments of various massive rocks are also present, noticeable among which are a porphyryte and a fine grained granite porphyry very similar to the porphyritic facies of the granite of the region, but showing no augite. The grit thus appears to be a rather impure sandstone with considerable interstitial matter, which has recrystallized as hornblende. This development of hornblende in the clastics of northeastern Minnesota is of interest as it is of so widespread occurrence. It has been noticed in the quartzites of the Animikie* and in the Ogishke conglomerate, and, as will be mentioned below, is very characteristic of the green schists and tuffs.

Green schist.

Within the area under consideration there occur certain green schists of a rather anomalous character. They are of a dull green color and are rather soft, crumbling easily under the hammer. These rocks have been often described in the reports on this region as "soft green schists" and "chloritic schists," but, as is shown below, they are essentially composed of hornblende.

These schists are found well developed in some places. A small belt occurs just north of Kekequabic lake in the E ½ section 34, T. 65 N., R. 7 W.; also at the west end of the lake in the N. E. ¼ section 4, T. 64 N., R. 7 W., along the N. ½ section 11, T. 64 N., R. 7 W., and on the south shore in the N. W. ¼ section 32, T. 65 N., R. 6 W. But by far the largest and most typical exposures are to be seen in a narrow belt along the north side of the lake in sections 35 and 36, T. 65 N., R. 7 W., and the S. W. ¼ section 31. T. 65 N., R. 7 W.; perhaps the best of these exposures occur on the small islands near the center of section 36, T. 65 N., R. 7 W.

*W. S. Bayley. Notes on the petrography and geology of the Akeley Lake region in northeastern Minnesota; Ibid., 19th (1890) Ann. Rept., p. 194, 1892.

These outcrops almost everywhere show a distinct schistose structure, which is more pronounced where the rock has weathered. There are also in many places clearly defined lines of sedimentation; these can be seen in great perfection on a little island in the S. W. ¼ section 35, T. 65 N., R. 7 W. And here, as well as at some other localities, there are numerous rounded green pebbles of about the same composition as the green schist. These pebbles are clearly brought out by weathering and wave action, being slightly more resistant to these agencies of destruction than the rock itself, which decays and crumbles readily. There are also occasionally seen quartz bebbles arranged in parallel lines, thus giving additional traces of original sedimentary planes.

The green schist is usually of rather fine grain and is sometimes so fine that it appears homogeneous. In the coarser varieties it macroscopically seems to be composed of small, glistening flakes in an unindividualized groundmass. Under the microscope the rock is seen to consist of closely crowded green hornblende crystals imbedded in a fine fibrous groundmass. These hornblendes are usually in short stout prisms but little elongated in the direction of the vertical axis. They are rarely more than half a millimeter in length and the average are not more than half this size. They are commonly not completely idiomorphic, although sometimes they are. The prismatic planes are, however, very generally quite distinct, but the terminal faces are not so often well developed and are usually entirely absent. The hornblende is of the usual green variety, although some crystals are inclined to a brownish shade. Its pleochroism is quite distinct, $\mathfrak{a}$ being light greenish yellow, $\mathfrak{b}$ olive green to brownish, and $\mathfrak{c}$ bluish green. The absorption formula is $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$, although the rays vibrating parallel to $\mathfrak{c}$ and $\mathfrak{b}$ are nearly equally absorbed, and the color is frequently almost the same in the direction of both of these axes.

The ends of many of the hornblende crystals, as stated above, show no terminal planes, but they have fibrous prolongations running out into the groundmass. These fibrous ends are commonly not sharply marked off from the crystal proper and no line can be drawn between them, the fringe being of the same color as the rest of the crystal and optically continuous with it. It however happens that some of the hornblendes, especially those of a brownish shade, show sharp terminal planes, beyond which is the fibrous growth optically continuous with the crystal; but this fringe is of a different shade from the crys-

tal proper, being greenish instead of brownish. These fringes are always confined to the ends of the crystals and are not seen on the prismatic planes

The fringes of hornblende fibers closely resemble the secondary enlargements of hornblende grains and crystals described by C. R. Van Hise* and they also appear very similar to those figured from the Menominee region of Michigan by G. H. Williams, who considers them not to be secondary enlargements but "the result of bleaching and fraying out of originally compact hornblende."† It seems to the writer that the fibrous rims in the green schist under consideration are due to enlargement or a second period of hornblende growth, as the rock is perfectly fresh and shows no evidence that the hornblende has suffered bleaching.

The groundmass of the green schist is quite fine and is composed almost entirely of interlacing fibers of hornblende. There are also small areas of colorless, weakly refracting, substance which is apparently saussurite; the hornblende fibers penetrate this in all directions.

The original nature of the green schist is not very evident. That it is a water deposit is, however, clear. As already mentioned it often shows distinct sedimentary lamination and the laminæ are frequently seen, where the rock has been more or less crumpled, running in wavy lines at various angles to the schistose structure. The difference between the laminæ appears usually only on weathering, as some are more resistant than others. One thin section cut across the lamination and schistosity, where these are parallel, shows many cross sections of hornblende, thus proving that a considerable number of the hornblende crystals have their vertical axes lying approximately parallel to the schistose planes of the rock. To the cleavage of these crystals is due, at least in some measure, the schistose structure of the green schists. This section also shows two laminæ, the only difference between them being that in one the hornblendes are noticeably larger and that there is a small amount more of the saussurite substance than in the other. It seems improbable that the fresh and sharply outlined crystals of hornblende should have been deposited in that state, and so the rock appears to have been entirely recrystallized from its original condition. If such is the case there would

*Enlargements of hornblende fragments; Amer. Jour Sci., 3, vol. xxx. pp. 231-235, Sept., 1885.

†The greenstone schist areas of the Menominee and Marquette regions of Michigan; U. S. Geol. Survey, Bull. No. 62, p. 126, fig. 19, 1890.

seem to have been two periods of hornblende formation, to the second of which belong the fibrous enlargements of the crystals and very likely the fibrous groundmass.

The occurrence of sharply outlined crystals of hornblende of secondary origin in a clastic rock has already been mentioned. Reusch* has described a conglomerate from Norway in which there are hornblende needles ("epigenetic hornblende") lying in the matrix of the conglomerate, and also running from the matrix into the pebbles, thus proving the secondary origin of the hornblende.

As to just what was the nature of the original sediment which formed the green schist it is impossible to decide, but it seems probable that it was a fine water deposited volcanic ash, now entirely recrystallized. This idea is strengthened by the fact that these green schists are rather intimately connected with the next rock type,—an undoubted tuff,—and the two grade together; and in the latter are also found similar crystallizations of hornblende.

Volcanic tuff.

Extending along the central part of the north shore of Kekequabic lake and separated from the water by a narrow belt of green schist, is a prominent ridge ending on the east in Mallmann's peak. This ridge is made of hard tough rock, which, excepting at its eastern end, is different from any rock in the vicinity. It varies much in general appearance but is usually of a greenish color with an aphanitic base in which are seen numerous lighter blotches and changes of color. Between these blotches, and sometimes in them, are black crystals of hornblende. Pyrite is also quite commonly seen. In certain places rounded and subangular pieces of quartz and argillyte are embraced in the rock, and it is also seen gradingin to the green schists. Parallel bandings similar to sedimentary laminæ also occur, sometimes quite abundantly, but usually the rock shows no structural planes of any kind, nor any schistose or slaty cleavage.

In thin section this rock varies much, but its fragmental character is easily discernible. The original nature of the fragments, which are usually angular, is, however, not very evident owing to alteration and the development of second-

* Die Fossilien fuehrenden krystallinischen Schiefer von Bergen in Norwegen, p. 50. Leipsic, 1883.

ary minerals in the rock, but it seems that a porphyryte forms most of these fragments. Between the fragments and forming the groundmass of the rock, and often in the fragments themselves. are many hornblendes similar to those in the green schist. And there are also areas of secondary hornblende filling in old crystal outlines; what these crystals originally were is not clear, although they probably were pyroxenes.

That the Keewatin rocks northwest of lake Superior are to a considerable extent composed of volcanic (effusive) material has been stated already by G. M. Dawson,* A. C. Lawson† and N. H. Winchell. Although the material of much of the Keewatin in Minnesota has been assumed to be volcanic tuff and finely divided, water-deposited ash, still the actual number of places where the rocks have been shown to be composed of such volcanic matter is very small. M. E. Wadsworth has described a few sections of fragmental volcanic rocks—porodytes‡—, and N. H. Winchell has given an account of an agglomerate from Ely.§ Aside from these the writer knows of no descriptions of rocks from the Keewatin of Minnesota that are clearly shown to be of volcanic origin. That some of the rocks about Kekequabic lake, especially the green schists, were composed of fragmental volcanic material has been suggested before.‖

Conglomerate.

While conglomeratic patches of very limited extent, holding only small pebbles, are found at various places in the rocks already described, especially in the green schists, still these areas have never been large enough or common enough to entitle the rock to be designated as a conglomerate. However, a conglomerate containing numerous rounded and closely crowded pebbles, which often reach a size of over a foot in diameter, occurs near the south shore of Kekequabic lake at its narrowest point. There has been no unconformity found between this rock and the finer grained non-conglomeratic rocks near it, although the bedding in the conglomerate is obscure; and it seems to grade into the other rocks by simple loss of its peb-

* British N. A. Boundary Commission, 1875.
† Geol. Surv. of Canada, vol. iii, pt. i, 1888.
‡ Ibid., Bull. No. 2, 1887.
§ Amer. Geol., vol. ix, pp. 359-368, June, 1892.
‖ N. H. Winchell. Geol. and Nat. Hist. Surv. of Minn., 16th (1887) Ann. Rept., p. 108, 1888.

bles. This conglomerate is part of what has been termed the Ogishke Muncie or simply the Ogishke conglomerate. It has been frequently described and discussed as far as our present knowledge of it will allow, and consequently it need not be further spoken of here. The reader is referred to a paper by the writer where full references are given to the descriptions of this conglomerate and to the ideas that have been advanced concerning its stratigraphic relationships.*

THE IGNEOUS ROCKS.

There are four distinct types of igneous rocks represented within the area treated in this paper. In order of their probable ages they are: porphyryte, granite, diabase and gabbro. Of these the first two have been made subjects of somewhat detailed investigation, the results of which are contained in the two following chapters. The other two types of igneous rocks are developed within the area studied only to a small extent, and they are therefore given but a brief description in this place.

Diabase.

Diabase is found in this area only in vertical dykes which do not form any very prominent features of the country. These dykes are of later age than, and cut all the other rocks of this region, with the possible exception of the gabbro. The most westerly occurrence of diabase is at the base of the small promontory in Kekequabic lake in the S. W. ¼ section 3, T. 64 N., R. 4 W. Here this rock was seen only in one place and the direction of the dyke is not known. A dyke thirty feet in width is found along the south shore of Spoon lake in the S. E. ¼ section 26, T. 65 N., R. 7 W.; its direction is N. 40° E., and it is again seen a short distance to the northeast cutting across a point on the north shore and forming the center of a low ridge. Just to the west of this place and on the north side of the same lake is a fine grained dyke three feet wide; this runs almost at right angles to the other. On the eastern half of Kekequabic lake are three dykes with a nearly north and south direction; each is seen on both sides of the lake. The most westerly is in the N. W. ¼ section 31, T. 65 N., R. 6 W., and the most easterly is seen on the north shore in the

* The stratigraphic position of the Ogishke conglomerate of northeastern Minnesota; Amer. Geologist, vol. x, no. 1, pp. 4-10, July, 1892.

S. W. ¼ section 29 and on the south shore in the N. W. ¼ section 32, T. 65 N., R. 6 W. The other crosses the lake just east of Mallmann's peak; it appears above the water twice in its course across the lake and forms two small islands; this dyke has been described by N. H. Winchell* and by A. Winchell.‡

Just east of the centre of section 32, T. 65 N., R. 6 W., is another dyke running north and south, which has been traced but a short distance. Near the southwestern end of Epsilon lake are two more dykes, the smaller one, fifteen feet wide, runs in a northwesterly direction and is seen on both sides of the lake. The other is the largest seen in this region, being over 150 yards in width. It is very coarse grained in the centre, and sends off small branching dykes into the surrounding rock.

A thin section of the diabase from the most easterly of the dykes that cross Kekequabic lake shows the rock to be a coarse ophitic aggregate of plagioclase and a pinkish augite. There is considerable iron ore, probably magnetite, present and large amounts of secondary hornblende have been developed, not only as replacements of part of the augite but also in numerous films all through the section. The plagioclase is in places undergoing alteration to sericite. A section from the larger of the two dykes on Spoon lake is of medium grain and contains a very large proportion of augite, which however does not show as pronounced a pinkish tinge as that in the other section. Much of the plagioclase appears cloudy in ordinary light and under crossed nicols is seen to have largely altered to sericite. Secondary hornblende is not as common as in the other dyke.

Gabbro.

This type of igneous rock occurs only along the southern side of the area studied. The gabbro is quite coarse grained and shows many variations, which have been described already quite fully, and no further mention of it need be made here except to refer to Irving's description§ and to those in the reports of the Geological and Natural History Survey of Minnesota.†

* Geol. and Nat. Hist. Survey of Minn., 15th (1886) Ann. Rept., p. 368, 1887. 16th (1887) Ann, Rept., p. 101, 1888.

‡ Ibid., 15th (1886) Ann. Rept., p. 153, 1887.

§ The copper-bearing rocks of Lake Superior; U. S. Geol. Survey, Mon. V, pp. 37-61, 1884.

† Especially Bulletins Nos. 2 and 6; also some of the Annual Reports.

However, it will be of interest to speak briefly of a peculiar rock, which is mapped as a contact rock of the gabbro. This has been mentioned many times in the reports of the Minnesota Survey as "muscovado." It is, as usually seen, a brownish, fine grained, granular, rock which easily crumbles under the hammer; this is, however, only the weather parts of the rock, and in fresh exposures it is dark gray, of granitic texture and rather fine grain. This rock is confined to the northern limits of the gabbro and is seen in many places along this line and to the south of it. It is now known that part of the rocks included under the term "muscovado" are altered portions of the Keewatin sediments, probably metamorphosed by the action of the gabbro. Such rocks can be especially well seen on the east shore of Gabimichigama lake in section 32, T. 65 N., R. 5 W. On the other hand it seems very probable that large parts of the so-called "muscovado" will be found to be fine grained gabbros;—perhaps a facies of the gabbro presented near its contact with the underlying rocks, or fine grained gabbros of a little earlier date than the main coarse grained gabbro mass. Sections of such rocks show them to be nothing but fine grained gabbros.

DRIFT DEPOSITS.

From the gabbro, which is of Keweenawan age, there are no evidences of any other geological formations having been deposited in this region until coming to the drift. However, near the northern edge of the gabbro and considerably farther west Cretaceous strata have been recently found and it is possible that these deposits once existed much farther east in northeastern Minnesota than they are now known.* Traces of glacial action are very evident in many rounded knobs of ice-scored rock and in scanty deposits of sand, gravel and boulders. The tops of the highest hills show glacial striæ and often are more or less strewn with foreign boulders. There are, however, no recognized moraines about Kekequabic lake, and wherever the drift is present it is at most of only a few feet in thickness.

*H. V. Winchell. Note on Cretaceous in northern Minnesota; Amer. Geologist, vol. xii, no. 4, pp. 220-223, Oct., 1893.

AGES OF THE DIFFERENT ROCKS.

The rocks around Kekequabic lake, excepting the gabbro and diabase, have been considered in the reports of the Minnesota Survey as belonging to the Keewatin; this is the Minnesota equivalent of the Lower Huronian, as that term is used by the United States Geological Survey.* To this series would be referred the slate formation, the green schist and the volcanic tuff, which seem intimately connected with each other and are probably the oldest rocks in the area studied. The conglomerate contains numerous well rounded pebbles, many of which are similar to some of the Keewatin rocks, and it seems to belong to a newer series, although as yet no unconformity has been seen between this conglomerate and the other rocks.

That this conglomerate is a conformable part of the Keewatin is the view of N. H. and A. Winchell, while Lawson holds the same view, but regards it as representing a newer infolded part of this series, probably separated from the rest of the Keewatin rocks by an unconformity. Van Hise considers the conglomerate to belonging to a newer series,—the Animikie (Upper Huronian),—which is separated from the Keewatin (Lower Huronian) by a marked unconformity. The writer is inclined to the view of Lawson, *i. e.* that the conglomerate is part of the Keewatin, probably separated from the lower part of that series by an unconformity, and that it is much older than the Animikie.†

An unconformity, considered to exist between Keewatin schist and Animikie slate, has been described by A. Winchell on the northeastern shore of Epsilon lake,‡ just outside the area mapped in this paper. This unconformity has not been recognized about Kekequabic lake.

From our present knowledge we have no positive proof that there is more than one series of clastic rocks in the Kekequabic lake area, but there are certain facts which suggest the possibility of two unconformable series being here represented. The clastic rocks of the whole region have been subjected to severe folding and have in many places acquired secondary structures, so that the exact structure and sequence can be determined

*Cf. C. R. Van Hise. Correlation Papers—Archaen and Algonkian; U. S. Geol. Survey, Bull. No. 86, 1892.

† References to the views concerning the age of the Ogishke conglomerate will be found in the writer's paper "The stratigraphic position of the Ogishke conglomerate of northeastern Minnesota;" Amer. Geologist, vol, x, no. 2, pp, 4-10, July, 1892.

‡ Geol, and Nat. Hist. Survey of Minn,, 16th (1867) Ann. Rept., p. 323, 1888.

only by careful and detailed work. Future investigations may show that the whole is one conformable series, or that there are two unconformable series, to the younger of which belongs the conglomerate, and perhaps some of the other rocks.

The porphyryte has been regarded as of Keewatin age and there is nothing to show that the granite cut rocks of a more recent age than the Keewatin. The gabbro is usually regarded as of early Keweenawan age. The age of the diabase dykes is not known; they were perhaps cotemporaneous with the great diabase intrusions in the Animikie, which have been referred to Animikie, Keweenawan, and perhaps even to Silurian* time.

The porphyrite and granite do not show the results of having been subjected to intense dynamic action, like periferal granulation of the grains or the production of a schistose structure, except that the quartz sometimes shows undulatory extinction. However, the harder and more resisting parts of the clastics,—the graywacke, volcanic tuff and conglomerate,—also often show no structures produced by dynamic agencies, but they were certainly present during the folding of the region. So the two igneous rocks just mentioned may be of earlier date than the folding. From his present knowledge the writer regards the porphyryte as cotemporaneous with the deposition of the volcanic tuff and the green schist, and the granite as dating from the folding. The diabase dykes are clearly later than both the porphyryte and the granite, and are also certainly of more recent date than the folding.

The following table gives the ages of the rocks represented around Kekequabic lake. On the left are given the age terms used by the Geological and Natural History Survey of Minnesota, and on the right those of the United States Geological Survey. However, as before stated, the diabase may not belong where it is placed, and the conglomerate, with perhaps some of its associated rocks, may prove to be later than the Keewatin (Lower Huronian). If the latter is the case, there were probably two periods of folding.†

Taconic	Keweenawan	Diabase Gabbro	Keweenawan	Algonkian
Archean	Keewatin	Conglomerate Slate formation Volcanic tuff Green schist Porphpryte Granite	Lower Huronian	

*A. O. Lawson. The lacoolitic sills of the northwest coast of lake Superior; Geol. and Nat. Hist. Survey of Minn., Bull. No. 8, p. 48, 1893.

†See also the table of Pre-Silurian rocks of Minnesota published elsewhere in this volume.

CHAPTER III.

THE GRANITE.

The granite, which forms the principal object of this investigation is of an unusual and interesting type, being an augite granite containing sufficient alkali to impart an acmite-like habit to the pyroxene, but not enough to prevent the crystallization of free silica. The author has already published a preliminary description of this granite, which description, however, is devoted only to the petrography of the rock.*

OCCURRENCE.

The granite, with the two exceptions mentioned below, is confined to a roughly oval area, whose major axis (east and west) is about three and a half miles; the minor axis being less than two. It occupies most of the S. W. ¼ section 31, T. 65 N. R. 6 W., the S. ½ of S. ½ section 36, T. 65 N., R. 7 W., nearly all of section 1, all the land in section 2 and most of the land in section 3, T. 64 N., R. 7 W. The only exceptions to the oval outline of the area occupied by the granite are: (1.) A narrow band of granite, or what appears to be such, running out from the main mass along the south shore of Kekequabic lake, in section 31, T. 65 N., R. 6 W. (2.) Small isolated granitic bosses found in the clastic rocks, mostly to the north of the main mass of the granite. The rock of these areas makes up the porphyritic facies of the granite. In this connection, and before proceeding farther, it might be well to state that the granite is separated into two principal facies,—a granitic and a porphyritic,—which are rather distinct in the field.

On all sides, except at the southwest, the outlines of the granite area can be pretty definitely traced, and we can feel sure that its surface area is about all exposed. But at the southwest the gabbro contact rocks come up to the granite. If

*Note on an augite soda-granite from Minnesota; Amer. Geologist, vol. xi, no. 6, pp. 383-388, June, 1893.

these rocks are part of the gabbro which extends over the old granite surface, it is possible that there is an area of granite now concealed under the gabbro and its contact rocks to the southwest. But this is rendered rather improbable for two reasons: (1.) The general outline of the granite area and the fact that the clastic rocks of the region are found both on the south and west would seem to indicate that they were continuous around the southwestern edge of the granite boundary. (2.) It is not yet certain that the gabbro contact rocks which here come up to the granite are not the clastics of the region metamorphosed. There are no other known exposures of granitic rocks within several miles of the Kekequabic lake granite, excepting one small outcrop (syenite) in the midst of the gabbro near the center of the S. W. ¼ of section 11, T. 64 N., R. 7 W.*

PARALLEL STRUCTURES.

One of the first features of the granite which attracts attention is its separation along roughly parallel planes. The layers thus formed vary from an inch to ten or more inches in thickness, and the same layer varies in thickness within a short distance. No difference in petrographical character between the different layers can be made out, nor is there any arrangement, macroscopically visible, of the constituent minerals of such a kind as to cause splitting along these planes. And there seems to be no tendency toward an indefinite separation into finer and finer layers. In some cases small quartz veins are to be seen between the different layers, but usually there is nothing visible except a simple undulating crack. Thin sections of the rock cut at right angles to this cleavage show no evidence of any parallel arrangement of the minerals nor of any microscopical faults or fault breccias, to which cause the rifting of certain granites is due.†

The cleavage of the granite of Kekequabic lake has been described and figured‡ but no explanation of its origin was given. It was provisionally called flowage structure, but there is no evidence of such a structure in the rock. It seems to

*Geol. and Nat. Hist. Survey of Minn., 20th (1891) Ann. Rept., p. 69, 1893.

†R. S. Tarr. The phenomenon of rifting in granite; Amer. Jour. Sci., 3, vol. xli, pp. 267-272, Apr. 1891.

‡Geol. and Nat. Hist. Survey of Minn., 15th (1886) Ann. Rept., pp. 361-362, figs. 51 and 52, 1887. 20th (1891) Ann. Rept., pp. 70-71, fig. 5, 1893.

the writer this separation into sheets is probably due to jointage caused by contraction in cooling. While this cleavage is in places very pronounced, it is still not to be seen over most of the granite area. It is found in its best development on some of the smaller islands in the western part of Kekequabic lake in section 3, T. 64 N., R. 7 W. Here the parallel layers dip toward the north at angles varying in different outcrops from 10° to 40°, but on the little point in the S. E. ¼ of S. W. ¼ section 2, T. 64 N., R. 7 W., the dip is toward the south 10° to 15°. No general direction nor regularity in this dip has been seen.

It will be noticed that in the previous descriptions of this granite it has been frequently called "fine syenitic gneiss," "chlorite gneiss" or simply "gneiss,"* thus implying that there was some evident gneissic structure in the rock. However, aside from that described above, the writer has been able to detect no evidence of any parallel structures in the rock; there are no alternating bands of different mineral composition, nor are the mineral grains uniformly elongated in a common direction. Wherever examined the rock presents a truly massive aspect. The only thing to suggest a parallel arrangement of the minerals is in small areas of the porphyritic facies of the granite, where some of the feldspar phenocrysts are arranged with their long axes roughly parallel, due to movement in the mass before solidification and after the formation of the phenocrysts. In support of the above statements concerning the absence of gnessic structure in the granite it may be well to quote the following from N. H. Winchell's second report on Kekequabic lake: "This [the granite] has been called *gneiss* this year and last, but it needs a word of qualification. It is not the real gneissic structure, or foliation supposed to be due to original sedimentary bedding. It has acquired a sheeted structure, but in general it is a massive rock, showing variations due to the original conglomeritic state of its materials, as already described. Where it passes into the porphyry it is more compact and more firm than when it is not porphyritic."†

The only other parallel structure heretofore noted in the granite is that due to traces of an original sedimentary banding —considering the granite as a highly metamorphosed conglom-

*N. H. Winchell. Ibid., 15th (1886) Ann. Rept., pp. 361-369, 1887. 16th (1887) Ann. Rept., pp. 149-156, 1888.
A. Winchell. Ibid., 15th (1886) Ann. Rept., pp. 69-82, 1887.

†Ibid. 16th (1887) Ann. Rept., p. 104, 1888.

erate. The remains of this structure were noted in one place, as follows: "There is visible sometimes not only a conglomeritic, but a sedimentary banded structure, dipping 80° from the horizon, south 10° west."* The writer can only say that he has been unable to find any traces of an original sedimentary banding, or anything that would suggest it, in the granite.

FIELD RELATIONS OF THE GRANITE.

In this section it is proposed to briefly outline the general relations of the granite, as seen in the field, to its own facies and to the other rocks by which it is surrounded.

Field relations of the granite to its own facies.

As already stated there are two important facies of the granite,—a normal granitic and a porphyritic. The porphyritic facies occurs in isolated bosses without the limits of the granite proper and is usually separated from it by the country rock. In a few places the two facies approach near to each other, but are not seen in actual contact. Here no evidence of a transition between the two is seen, each retaining its own characters as near together as they were exposed. Only one contact has been seen between these two facies of the granite; here in a small exposure branching vein-like forms of the granite porphyry cut the granitic facies From this it would appear that the porphyritic facies is of some later date than the main mass of the granite. The two rocks agree so well in chemical and mineralogical composition, which will be mentioned later, that it seems impossible to consider them as anything but parts of the same magma. The writer is inclined to think that the porphyritic facies is of but little later date than the granitic facies and perhaps was erupted before the complete cooling of the latter.

In the N. W. ¼ section 2, T. 64 N., R. 7 W., is a small island made up mostly of the normal granite, but with a porphyritic aspect. At the north end of the island is a dark gray to greenish rock, which is called the poikilitic facies of the granite. This is cut in all directions by vein-like forms of the granite and angular fragments of the dark rock are found imbedded in the granite mass. The granite where it cuts the other rock is

*Ibid., 15th (1886) Ann. Rept., p. 362, 1887.

somewhat finer grain than at a short distance from this place.

A peculiar facies of the granite is found in the narrow strip, which runs along the south shore of Kekequabic lake in the east half of section 31, T. 65 N., R. 6 W. This is somewhat different from the normal granite, but nevertheless seems to grade into it. This facies of the granite is called the hornblendic facies.

Aside from the four phases of the granite already mentioned, there is another,—the syenitic facies. This is not as distinctly separated from the normal granite as are the others, but it forms an important part of the granite mass. In many places by a simple gradual loss of the quartz, the granite passes into an augite syenite. These areas of .syenite occur most frequently on the hills in sections 1 and 2, T. 64 N., R. 7 W.

Field relations of the granite to the surrounding rocks.

Transitions.—In former descriptions it has been supposed that this granite in places passes gradually into the graywackes and conglomerates of the region. At two localities there has been found a gradual passage from the granite to rocks macroscopically resembling fine graywacke or graywacke slate. The first of these is on the northern side of the narrow point which projects from the west shore of Kekequabic lake in the S. W. ¼ of N. W. ¼ section 3, T. 64 N., R. 7 W. Here within a distance of 30 feet there is a gradual transition from distinct fine grained granite into a rock which resembles the graywacke slates of the region, but it shows no lamination and the slaty structure is not well developed. Near the base of the promontory in the S. W. ¼ of S. W. ¼ section 29, T. 65 N., R. 6 W., is an apparent transition in a distance of a foot or two from the phorphyritic granite to a graywacke-like rock. A series of specimens has been collected from both of these places and mention of them is made in the section on the origin of the granite, but it may be well to state here that the microscopical examination in no way confirms the idea of a passage from a clastic rock to the granite.

Contacts.—Around the edge of the main mass of granite several exposures have been found showing contacts of this rock with the surrounding sediments. Perhaps the one best suited for the determination of the relations of the granite to the country rock is near the center of the W. ½ of S. E. ¼ section

1, T. 64 N., R. 7 W. The plan of this exposure is shown in the accompanying sketch (Fig. 2), which makes the relations of the

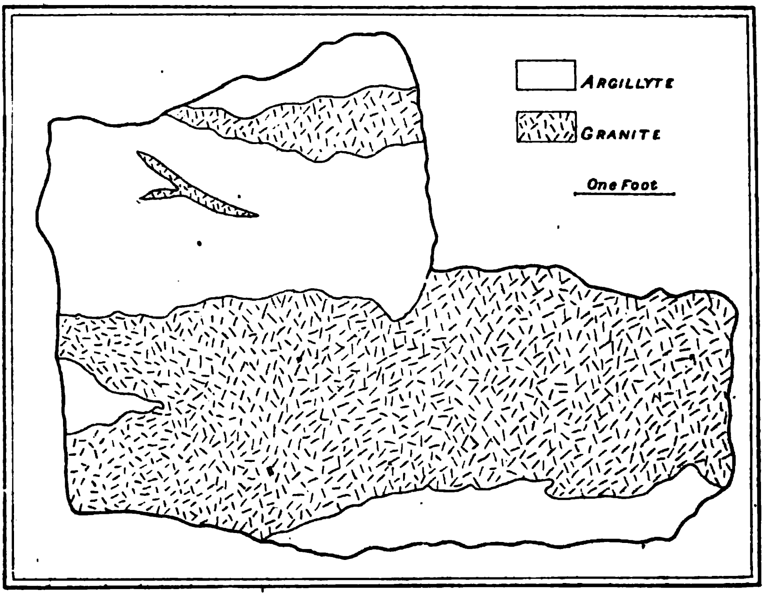


FIG. 2. Contact of granite and argillyte; W. ½ of S. E. ¼ section 1, T. 64 N., R. 7 W.

two rocks sufficiently plain. The granite is quite sharply marked off from the country rock, which is here a dark argillyte in which the bedding is obscure, although approximately parallel with the main line of contact. In the other contacts the eruptive character of the granite in the country rock is not so clearly shown, but the line between the two rocks is quite distinct and the granite is of a finer grain at the contact than at a distance of a few feet from it. In the southwest quarter of section 31, T. 65 N., R. 6 W., a mass of argillyte, more or less altered, is seen included in the granite, but sharply marked off from it.

The porphyritic facies of the granite is found in contact with the green schist and conglomerate in several places. It usually sends no apophyses into these rocks, but its later age is shown by its uniformly finer grain at the contact lines.*

On a little point on the north shore of Kekequabic lake (S. W. ¼ section 34, T. 65 N., R. 7 W.), the dark argillyte is cut by a small irregular dyke of granite porphyry, which sends many stringers into the argillyte and also includes fragments of it.

*Two of these contacts have been figured in the 15th (1886 Ann. Rept., Geol. and Nat. Hist. Survey of Minn., pp. 154, 367, 1887.

PETROGRAPHICAL DESCRIPTION OF THE GRANITE.

Macroscopical.

In the field there are seen to be two quite distinct facies of the granite—the normal granite andthe granite porphyry. These present some microscopical differences, but they have many characters in common. The normal granite is of a medium or fine grain and a dull pinkish color. This color is quite characteristic of the rock as seen in most of the outcrops; it is due to the color of the feldspar which is the predominating mineral. The texture is firm and compact. In some of the finer grained phases it is almost impossible to distinguish any mineral other than feldspar, but in the coarser phases are also seen grains of a darker mineral, which proves to be augite, and quartz. However the last is not very evident in hand specimens. In some places, noticeably in the N. W. ¼ of N. W. ¼ section 2, and the promontory in the S. W. ¼ of S. W. ¼ section 3, T. 64 N., R. 7 W., the granite is sub-porphyritic with feldspar crystals. These phenocrysts are often, especially at their centres, of a little lighter color than the non-porphyritic feldspar. This granitic facies makes up the main mass of the granite; it varies little in different exposures.

The granite porphyry is found only in small isolated areas in the clastic rocks and near the edge of the area of normal granite. It is distinguished by its fine, usually aphanitic, groundmass and its decidedly porphyritic aspect, which is due to numerous white or flesh colored feldspar phenocrysts scattered indiscriminately through the rock mass. There are also minute short stout augite prisms and occasional brilliant black biotite scales to be seen in the groundmass. The feldspar phenocrysts vary in size in the same hand specimen from almost microscopic dimensions to those ten or fifteen millimeters in length. The smaller ones are often very closely crowded together and are sometimes arranged more or less in lines of flow. At one locality these feldspars are very large and conspicuous, sometimes reaching a length of over twenty millimeters. The only exception to the white or flesh color of these phenocrysts is on the northern side of the small island in the S. W. ¼ of N. W. ¼ section 3, T. 64 N., R. 7 W., where the feldspars are of a reddish color. Plate I, Fig. 2, shows the appearance of a pronounced phase of the granite porphyry.

What is termed the hornblendic facies of the granite is found only in a narrow strip along the south shore of Kekequabic lake in section 31, T. 65 N., R. 6 W. It has a fine grained gray groundmass whose constituent minerals are not readily distinguishable. In this are usually scattered small whitish subporphyritic feldspars and less evident black prisms of hornblende. This rock is different from the main mass of the granite in several respects, and the writer does not feel entirely satisfied that it is part of the granite, but it seems to be such and is placed here as a hornblende facies of the granite.

As already mentioned (pp. 40-41) the normal granite is seen cutting a dark gray to greenish rock on the small island in the N. W. ¼ of N. W. ¼ section 2, T. 64 N., R. 7 W. This rock has a dull greenish groundmass in which are imbebbed noticeable flakes of biotite and less evident augite prisms. Even in hand specimens there are seen to be certain areas of the groundmass, each of which reflects the light and in which are biotite and augite individuals. The rock is consequently called the poikilitic* facies of the granite, but it is possible that this is not part of the granite mass. It is known only from the northwest side of this small island.

A noticeable feature of the granite in all its facies is the occurrence of small rounded, subangular and angular areas, which are sharply marked off from the rest of the rock. They vary from half an inch to two inches in diameter, rarely being larger. They are composed usually of aggregations of rather coarsely crystallized hornblende, or augite. Frequently, however, these dark areas are fragments similar to the country rocks—argillyte and green schist. These more or less rounded form are very abundant in certain parts of the hornblende granite. In fact in one exposure it is almost impossible to find any surface a foot square which does not contain one or more of them, and some areas of this size include as many as twenty.† In the granite proper and the porphyritic facies these rounded forms are not so abundant, still they are seen rather frequently. In the former reports on this granite these forms have been regarded as the remains of pebbles in a conglomerate, which was considered to be the original character of the rock now a granite.‡ It also seems very possible to refer some of these forms to basic secretions, which are common to

*See G. H. Williams. On the use of the terms poikilitic and micropoikilitic in petrography; Journal of Geology, vol. 1. no. 2, pp. 176-179, 1893.

†Geol. and Nat. History Survey of Minn., 20th (1891) Ann. Rept., p. 79, 1893.

‡N. H. Winchell. Ibid., 15th (1886) Ann. Rept., pp. 362, 363, 1887.

very many granites, while others, on account of their petrographical character, can be regarded as inclusions of fragments of the surrounding rocks.

Chemical.

Two analyses have been made—one of the normal granite (I in the table of analyses) and the other of the granite porphyry (II). It will be seen that the two facies agree quite closely in chemical composition and that in each the proportion of soda is much larger than that of potash; in the granite proper the ratio of soda to potash is 1.8:1 and in the granite porphyry 2.4:1. Using the term "soda-granite" as a true granite which contains a larger amount of soda than potash, this rock would belong to the series of soda-granites. These have been reported from several localities in Europe, but as yet have been rarely found in America. W. S. Bayley* has described a granite which contains large amounts of anorthoclase from Pigeon Point, Minnesota, on the north shore of Lake Superior; this was found in connection with a quartz-keratophyre. And N. H. Winchell has recently published (see VI in the table of analyses) an analysis of a red granite from Rice Point, Duluth, in which the proportion of soda is very

ANALYSES OF SODA-GRANITES.

	I.	II.	III.	IV.	V.	VI.
SiO_2	66.84	67.42	68.00	70.69	72.42	75.78
TiO_2	.....	.....	.....	.....	0.40	.....
P_2O_5	tr.	0.07	.....	.....	0.20	.....
Al_2O_3	18.22	15.88	16.18	15.20	13.04	11.09
Fe_2O_3	2.27	1.37	3.68	3.76	0.68	2.09
FeO	0.20	1.14	0.65	.....	2.47	.....
MnO	.....	tr.	.....	.....	0.09	.....
CaO	3.31	3.49	4.05	3.31	0.66	0.86
MgO	0.81	1.43	0.95	0.45	0.58	0.65
K_2O	2.80	2.65	2.04	2.31	4.97	1.06
Na_2O	5.14	6.42	4.32	4.69	3.44	6.43
H_2O	0.46	0.05	.....	0.56	1.21	1.82
Totals	100.05	99.92	100.49	101.07	100.37†	99.78

large; this rock is a hornblende granite of medium grain. These two soda-granites are from the Keweenawan. A soda-granite

*A quartz-keratophyre from Pigeon Point and Irving's augite syenites; Amer. Jour. Sci., 3, vol. xxxvii, pp. 54-62, Jan., 1889.

†Including traces of Li_2O and Cl and 0.15 per cent of BaO.

from Westchester county, N. Y., has been mentioned by J. D. Dana*, but G. H. Williams† has shown that this is properly a mica diorite.

The analyses of both facies of the granite under discussion and of several other soda-granites are given in the accompanying table. I is the normal granite from Kekequabic lake, Minnesota; No. 551G of the Minnesota Survey series. II is the porphyritic facies of the same; No. 86G. III is a soda-granite from Donegal, Ireland.‡ IV is the Aughrim (Ireland) soda-granite.§ V is the rock from Pigeon Point, Minnesota.‖ VI is the red granite from Rice Point, Duluth.**

In comparison with the last four analyses given in the above table and other published analyses of soda-granites,†† the rock from Kekequabic lake is seen to be lower in the amount of silica and usually higher in soda than other granites of this series. The large proportion of soda finds expression in the composition of the augite, as well as in that of the feldspar, as will be seen in the analyses of these minerals.

There is reason to think that soda-granites will be found more extensively developed in the Lake Superior region than has been supposed heretofore. It seems that some of the augite syenites from the Keweenawan, as already suggested by W. S. Bayley‡‡, may fall into this class, and there are numerous dykes in the Keewatin of northeastern Minnesota, described as quartz porphyries and syenite porphyries§§, a careful study of which will probably show that their feldspar is largely anorthoclase.

*Geological relations of the limestone belts of Westchester county, New York; Amer. Jour. Sci., 3, vol. xx, p. 198, Sept., 1880.

†The gabbros and diorites of the "Cortlandt series" on the Hudson river near Peeksville, N. Y.; Amer. Jour. Sci., 3, vol. xxxv, pp. 443-444, June, 1888.

‡S. Haughton. Experimental researches on the granite of Ireland. Pt. iv. On the granites and syenites of Donegal; with some remarks on those of Scotland and Sweden; Quar. Jour. Geol. Soc., vol. xx, p. 269.

§W. J. Sollas. Contributions to a knowledge of the granites of Leinster; Trans. Royal Irish Acad., vol. xxix, pt. 14, p. 471, 1891.

‖W. S. Bayley. *Op. cit.*, p. 59.

**N. H. Winchell. The Norian of the Northwest; Geol. and Nat. Hist Survey of Minn., Bull. No. 8, p. xxxiii, 1893.

††A. Gerhard. Neues Jahrbuch f. Min., Pet. u. Pal., 1887, II, pp. 267-275.

‡‡ *Op. cit.*

§§ U. S. Grant. Geol. and Nat. Hist. Survey of Minn., 20th (1891) Ann. Rept.. pp. 45, 48, 49, 51, 57, 58, 1893.

As this paper is going to press two analyses of acid igneous rocks from northeastern Minnesota have been completed by Mr. A. D. Meeds, Instructor in Chemistry in the University of Minnesota. Both of these show a considerable excess of soda over potash. The analyses are as follows:

Mineralogical.

The minerals of granite have been described so frequently and so exhaustively that it is not necessary nor advisable to attempt any complete description of all the minerals composing this granite. Consequently only one of them,—the augite,—will be spoken of in any detail, but an analysis and specific gravity determinations of the feldspar are given. The minerals comprising the rock can be divided into two classes, essential and secondary. In the order of their importance and abundance they are:

Essential	Feldspar (largely anorthoclase.) Augite. Quartz. Hornblende.	Accessory	Biotite. Apatite. Sphene.

As to the time of crystallization they are as follows: (1) Sphene and apatite. These are not found in contact so that nothing can be said as to their relative ages; they are both older than the other minerals. (2) Biotite, hornblende and augite. The relative ages of these are not clearly shown, but the biotite seems to be the oldest. (3) Feldspar. The only case where this is of as late a crystallization as the quartz is in the groundmass of the granite porphyry. (4) Quartz. Later than all the others, excepting the feldspar in the case just mentioned.

Feldspar.—The feldspar is much more abundant than any of the other minerals; it makes up half and sometimes at least three fourths of the rock mass; in the more basic (syenitic) parts of the granite it reaches its fullest development as regards amount.

Orthoclase is seen frequently in the normal granite and is very abundant in the hornblendic facies, but it never forms phenocrysts. Over two thirds of the feldspar is triclinic; it

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	H_2O	Totals.
I.	69.70	18.72	0.65	0.79	2.25	0.45	1.68	5.01	0.71	99.96
II.	69.34	17.25	2.46		3.43	1.18	0.71	4.33	1.17	99.87

I is a quartz porphyry (No. 417G; 20th Ann. Rept., p. 57) from a dyke in the "greenstone" of the Kawishiwi river, N. ½ N. E. ¼ sec. 21, T. 63—10 W. This rock has a micrograniti c groundmass in which are large phenocrysts of feldspar and quartz; a few small areas filled with chlorite and epidote are present, but what the original ferro-magnesian constituent was is not clear.

II is a characteristic specimen of the Saganaga granite (No. 686 G; 20th Ann. Rept., p. 88) from Saganaga lake, S. W. ¼ N. E. ¼ sec. 22, T. 66—5 W. This rock is a coarse grained hornblende granite.

shows the usual polysynthetic twinning according to the albite law, and in some cases the microcline structure is developed to a small extent. Zonal structure in the plagioclase is quite common, especially in the porphyritic crystals. The feldspar is always more or less cloudy due to incipient alteration, but the resulting minerals are not usually discernible, the cloudiness being due to amorphous opaque white areas; in the orthoclase alteration to sericite is common.

On separating the powder of a fresh specimen of the normal granite (No. 551 G.) by means of Thoulet's solution the larger proportion of the feldspar fell between a specific gravity of 2.58 and 2.62, which would indicate that the mineral was a mixture of the orthoclase and albite molecules; and the analysis, as here given, shows that it belongs to the anorthoclase series.

ANALYSIS OF FELDSPAR.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	H_2O	Total
67.99	19.27	0.82	0.75	0.02	3.05	6.23	0.90	99.03

It is to be noticed that the silica percentage is larger than is required by the amount of soda, potash and lime present. This is probably due to the fact that a small amount of quartz was so intimately intergrown with the feldspar that certain grains of the feldspar powder contained some quartz. From the analysis it is calculated that this feldspar is an *anorthoclase* with approximately the composition $Or_5\ Ab_{14}\ An_1$.

The specific gravity of several of the feldspar phenocrysts of the granite porphyry was determined; it ranges from 2.59 to 2.60. This, together with the analysis of the whole rock (II in the table of soda granite analyses), is sufficient proof that these phenocrysts, which make up about half the rock mass, are also *anorthoclase*.

Augite.—The augite is the most interesting mineral in the rock, as granites in which this is the chief ferro-magnesian constituent are comparatively rare. Augite makes up from five to twenty per cent of the whole rock and in the majority of sections is, besides the feldspar and quartz, about the only mineral present. It reaches its best development and is found in the least altered condition in the granite porphyry; accordingly the description of this mineral will be confined mostly to that occurring in this porphyry on the promontory at the southwest corner of section 29, T. 65 N., R 6 W., where this facies of the granite is seen in its best and most characteristic

development. (Nos. 86G and 1094 of the Minnesota Survey series.)

The augite occurs in short stout prisms, whose length is half a millimeter or less; rarely larger crystals, one to three millimeters in length are seen. The crystals are generally completely idiomorphic, but occasionally the terminal planes are lacking, or are very poorly developed. The prismatic planes are the unit prism, the orthopinacoid and the clinopinacoid. The terminal faces, which are usually present, are the basal plane and the orthodone $P\overline{\infty}$ while the unit pyramid and a clinodome can sometimes be recognized, but usually there is a tendency to a rounding off of the edges basal plane and the orthodome $P\overline{\infty}$. The cleavage is well developed in thin sections and parting is usually not seen, but in one case (see Fig. 4) it is quite noticeable. An attempt was made to measure the angles on some of the larger augite crystals detached from the rock, but the faces gave such imperfect reflections that no satisfactory results were obtained.

In transmitted light the augite is of a bottle green color, but there are parts of some crystals which are colorless and entire colorless individuals are sometimes seen. A slight pleochroism is to be noticed in many sections, $\mathfrak{a}$ and $\mathfrak{b}$ being bottle green and not distinguishable from each other, while $\mathfrak{c}$ is a yellowish green. The absorption is $\mathfrak{a}=\mathfrak{b}>\mathfrak{c}$.

Zonal structure is rather common; in such cases the core of the crystal is usually colorless, or of a lighter green than the outer rim. The colorless centres occasionally pass gradually into the colored rims, but generally the two are separated by a pretty distinct line. The outlines of these colorless cores are irregular and are seldom parallel to any crystallographic planes. The cleavage lines run uninterruptedly from one part of the crystal to another, and in sections cut parallel to the zone of the ortho-axis the extinction direction of both parts of the crystal are parallel, but in sections which are inclined to the ortho-axis, the extinction directions are differedt in the two parts of the crystal. Moreover, in one section, cut parallel to the clinopinacoid, parting parallel to the basal plane is seen, and this runs straight through the colored rim and the colorless core. From these facts it is seen that the two parts of the crystal have the same crystallographic axes, *i. e.* are parallel growths, but that the axes of optical elasticity, excepting the one coincident in direction with the ortho-axis, do not have the same directions in the two parts of the crystal.

The green crystals and rims have a lower index of refraction, lower double refraction and a smaller extinction angle than the colorless augite, (the extinction angle measured being that between $\mathfrak{a}$ and c in acute angle b). The dark green crystals are more pleochroic than the lighter ones, and the colorless ones show no pleochroism. These facts indicate that the green crystals and rims contain more of the acmite molecule than the colorless parts. (That the augite contains a considerable amount of the acmite molecule is shown by the analysis given below.)

The extinction angle of the colorless augite in sections parallel to the clinopinacoid runs as low as 37°, although usually higher than this; this is an angle of 53° as the extinction of augite is usually measured, *i. e.* $\mathfrak{c}$ to c in obtuse angle b. In

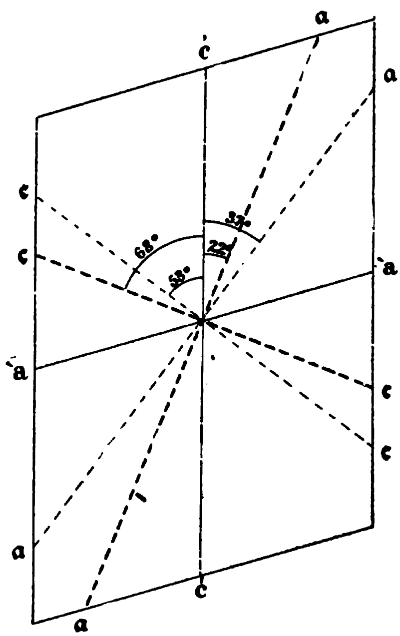


Fig. 3. Diagram showing the relative positions of the crystallographic and optical axes in the green and colorless augite.

the green crystals and rims $\mathfrak{a}$ is inclined about 22° to c, but in one section it is as low as 18°. The positions of the axes of elasticity with reference to the crystallographic axes are shown in the accompanying figure; the axes of elasticity of the colorless variety being represented by the lighter dotted lines.

While in the zonal crystals there are usually only two parts, which are of different optical orientation, in a few there are more than two such areas. To illustrate parallel growths of this kind the following figure (4) is introduced. It shows part

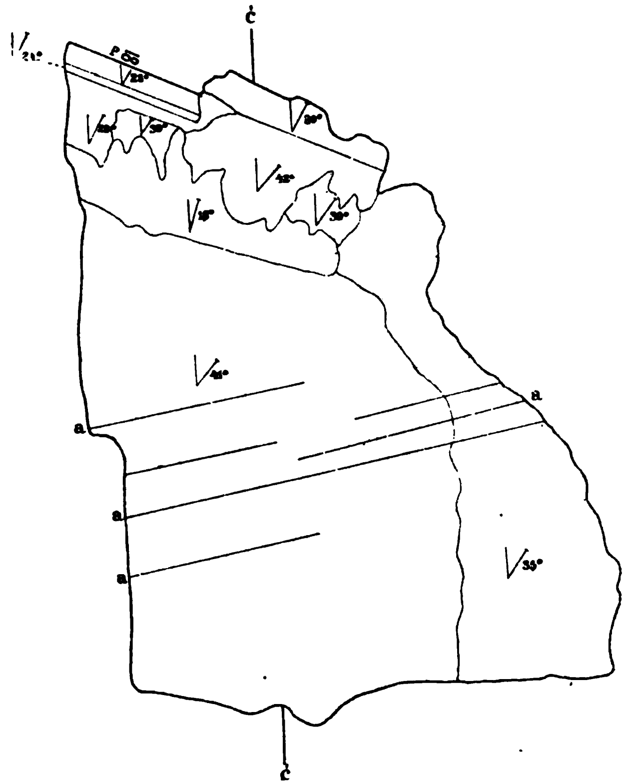


Fig. 4. Section of augite crystal showing areas of different optical orientation.

of a large crystal of augite cut parallel to the clinopinacoid. The extinction and outlines of the different parts are represented rather diagrammatically, as the different zones are not always separated by a sharp line. The lines *a a* represent the parting parallel to the basal plane. The extinction angles given are those of α against *c*. The large central part of the crystal is colorless and the rest is greenish; the small irregular area with an extinction of 18° is yellowish green and distinctly pleochroic.

A typical fresh specimen of the porphyritic granite was powdered and the augite separated and analyzed. This augite is fresh and unaltered and the powder used (which has a higher

specific gravity than 3) is quite pure, as in this specimen of the granite the only other minerals present were feldspar and quartz with a few minute fibers of secondary hornblende. The analysis is here given. Assuming that this represents an isomorphous mixture of the diopside, heddenbergite, acmite and

ANALYSIS OF AUGITE.

SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	H_2O	Total.
53.19	2.38	9.25	5.15	17.81	9.43	0.38	2.63	0.01	100.23

fassaite molecules and calculating their relative proportions we get approximately the following result:

Diopside, $Mg\,Ca\,Si_2O_6$	47	per cent.
Heddenbergite, $Ca\,Fe\,Si_2O_6$	27	" "
Acmite, $\dddot{Na}\,Fe\,Si_2O_6$	21	" "
Fassaite, $Mg\,Al_2\,SiO_6$	5	" "

In the considerable percentage of the acomite molecule this augite approaches in composition the pyroxene of the more alkaline rocks, the eleolite syenites.* This analysis very probably represents quite well the usual composition of the green augite, as the proportion of zonal crystals, with colorless centres, and entire colorless crystals is small. The colorless augite is very similar to that of the well known augite granite from Laveline in the Voges.

Quartz.—This mineral does not play as important a part in the rock under consideration as it does in most granites. It rarely forms more than a fourth of the rock mass, and, while usually more abundant than the augite in the normal granite, it is not always so. Quartz occurs in small irregular areas in the granitic facies of the rock, and often shows undulatory extinction and sometimes has been slightly fissured. It is never found in phenocrysts in either facies of the granite, and in the granite porphyry is only in minute grains in the groundmass.

Hornblende.—Original hornblende is found only in the hornblendic facies of the granite and in one exposure of the granite porphyry. Here there are some cross sections which show the characteristic planes of a hornblende cross section, but in some cases it seems to be secondary. The hornblende is of the usual green variety.

* Cf. A. Merian. Studien an gesteinsbildenden Pyroxenen; Neues Jahrbuch f. Min., Pet. u. Pal., B.B. III. pp. 252-315, 1885.

Secondary hornblende is of quite universal occurrence in all facies of the granite. It has usually developed in small green fibers, which penetrate the rock in all directions, and is frequently seen in fibrous growths around the ends of the augites and sometimes replaces whole crystals of this mineral with a fibrous aggregate. Where the rock has been much altered the hornblende often occurs in delicate sheaths of fibers much resembling those figured by G. H. Williams* in certain altered greenstones.

Accessory minerals.—Sphene and apatite occur in small amounts in the normal granite and in the granite porphyry; the apatite is in short stout prisms rather than in elongated ones. Biotite occurs in some sections of the granite porphyry and in a few cases is quite abundant; it is in small flakes usually surrounded by magnetite grains. Biotite is very common in the poikilititic facies of the granite.

Structural.

The different facies of the granite already spoken of,—the normal granitic, the porphyritic, the hornblendic and the poikilitic,—are characterized by structural differences.

The normal granite is usually of a truly granitic texture, but in some cases there are two generations of feldspars, the first being mostly idiomorphic, although not generally very sharply separated from the second generation as regards size. Occasionally there is a slight tendency for the fieldspars, when in only one generation, to assume a partially idiomorphic form.

The porphyritic facies has already been mentioned as characterized by numerous large and small phenocrysts of feldspar and smaller ones of augite. The groundmass as a rule makes up much less than half of the rock and is composed of a microgranitic aggregate of quartz and feldspar. The latter mineral is not usually polysynthetically twinned and thus would seem to be orthoclase.

The hornblendic facies is characterized not only by the presence of original hornblende, but also by the almost universal tendency of the feldspars to assume an idiomorphic development. This latter character is perhaps more striking than the presence of hornblende.

*U. S. Geol. Survey, Bull. No, 62, pl. XVI, fig. 1, 1890.

The poikilitic facies of the granite is strictly an augite-biotite syenite, as no quartz is present. The rock is composed of large, irregular, interlocking areas of feldspar, in which are imbedded numerous biotite scales and colorless to greenish augite prisms, thus forming a very beautiful example of the poikilitic structure. In this case it is noticeable that the grains and crystals of varying optical orientation included in an optically continuous area of feldspar are of two species instead of one, as is usually the case in rocks which show the poikilitic structure. The feldspar areas are often a quarter of a inch across and can be distinctly seen in hand specimens. A more careful and detailed study of this peculiar rock would probably bring out facts of interest.

THE ORIGIN OF THE GRANITE.

In the reports on the geology of the region about Kekequabic lake the granite has been regarded as of metamorphic origin. This has been maintained by N. H. and A. Winchell, and from their reports it would seem that their ideas are as follows: The granite is a result of the recrystallization *in situ*, under conditions of partial or complete aqueo-igneous fusion, of the sedimentaries of the region,—the graywackes and conglomerates. The more or less rounded foreign pieces in the granite are the original pebbles of the conglomerate. The granite was in some places plastic enough to allow it to be intruded into the surrounding rocks, but this intrusion was only very local and limited in extent, and the intrusive rock was not moved far from its original place. The main mass of the rock has not been moved at all, but is simply portions of the graywackes and conglomerates altered *in situ*. There are gradations from the granite to these clearly clastic sediments and the granite is not sharply marked off from the surrounding rocks, except in the few places where it has been intruded into them.

The facts, which are urged as sustaining the above idea as to the origin of the granite, seem to be four in number, as follows: (1) Presence of ancient but partially obliterated lines of sedimentation in the granite. (2) Presence of pebble forms in the granite. (3) Transitions from the granite to the clastic rocks. (4) Presence, in the immediate vicinity, of altered clastic rocks resembling the granite.

In regard to the presence of old lines of sedimentation in the granite, or anything to suggest such lines, the writer can only say that he has been unable to see any such, although he has carefully searched for them. In fact he has seen no structures in the granite which could be referred in any way to old lines of sedimentation.

That there are numerous rounded, sub-angular and angular pebble-like forms in the granite has already been stated. These are more abundant near the edge of the granite mass and in the small bosses of granite porphyry; this is a significant fact and agrees well with the explanation that many of these foreign pieces are inclusions of the country rock. In fact there is just as much reason, (to the writer there seems more,) for assuming that these pebble-like form are basic secretions in the granite, or are inclusions of the country rock, as there is for assuming them to be the remains of pebbles in an altered conglomerate.

Two apparent transitions from the granite to a seemingly sedimentary rock have already been mentioned (page 37). In the field these transitions could be traced quite well, but the rock into which the granite graded, while resembling the sediments of the region, still could not be proved to be a clastic rock. A microscopical examination of thin sections of a series of specimens taken to illustrate these transitions shows that the apparent sedimentary end of the series and also all parts of it reveal no evidence of an original clastic nature, in fact their characters are those of fine grained portions of the granite. The conglomerate and graywacke, into which the granite has been supposed to grade, show in thin section undoubted clastic characters, and in all the sections examined there is no occasion to confuse these rocks with the granite.

A mile to the east of Kekequabic lake are found small areas of altered clastics, which, in some characters, resemble the granite. Here the remains of sedimentary planes are visible, and the rock in hand specimens and in sections is seen to be somewhat similar to the granite, especially as regards degree of crystallization. Rock like this is, however, not found in a position intermediate between the clastics, from which it is derived, and the granite, as would be expected to be the case And it is well known that beds of certain altered clastics (gneisses) often closely resemble in hand specimens and in sections the granites which cut them, but this resemblance is no proof that the two rocks are of like origin and are parts of the same mass.

From the above it will be seen that the arguments for the derivation of the granite from the clastics of the region are, to say the least, rather unsatisfactory. Indeed the facts seem as susceptible of explanation on the idea that the granite is eruptive as that it is a part of the altered clastics. Moreover, there are other facts which point very strongly toward the eruptive origin of the granite.

Contacts have been described (page 37) which show that, at least at these localities, the granite plays an eruptive role. Here the granite has come into its present position in relation to the country rocks since their deposition, and it penetrates them in irregular dykes, and in one place includes undoubted fragments of the rock with which it comes in contact. Where contacts of the granite with the surrounding rocks occur the latter have been somewhat altered, although not very greatly, and a mass of the argillite enclosed in the granite is rendered gneissoid near its edges. Contact metamorphism is, however, not very marked. At these contacts the grain of the granite is finer than at a short distance from the contract line.

That the granite is of a different character from the surrounding rocks is well shown by the ease with which it is separated from them. In no place has a gradation from any of the sedimentary rocks to the granite been established. In the field it has been possible to map the limits of the granite much more accurately and easily than any of the sedimentary rocks, the accuracy of the outlines of the granite depending only on the number of exposures to be found. No rocks intermediate in position or character between the granite and the clastics have been observed in the area mapped. The sharpness with which the granite is everywhere separated from the surrounding rocks is best seen where the porphyritic facies comes in contact with or is seen near the dark argillytes. This fact that the granite is everywhere so sharply and so distinctly separated from the surrounding clastics is a very weighty proof that it is not a part of these clastics.

It is easy to imagine sediments buried so deeply and under such conditions of pressure and temperature in the presence of water that they would be converted into completely crystalline aggregates. We have many such instances, and it is undoubtedly true that many gneisses were formed in this way, but here it is to be noticed that a degree of crystallization, as complete as in granites, is often attained without the obliteration of certain structural planes in the rock,—i. e. there are rapid alter-

nations of bands of different chemical and mineralogical composition which are very distinctly separated from each other. Here there seems to have been practically no interchange between different parts of the mass. But if we assume that the granite under consideration, in which there are no alternation of bands of different composition, is of like origin, it seems necessary to assume that the fusion (if this word may be used) was so complete that the mass took on a uniform composition throughout, for it is hardly conceivable that a mass of sediments which shows a section three and a half miles long by two wide should be of a uniform composition throughout and that this mass should be sharply separated, both along and across the strike, from sediments which do show this variation in composition. Moreover it seems impossible that a mass which has been so complete altered *in situ* should be so sharply separated from the rocks from which it is supposed to have been formed and which still show their original clastic characters. Again, it seems impossible that the pebbles in a mass, which has been so profoundly altered and in which there has been so complete an interchange between its different parts, should not have been entirely obliterated, instead of still retaining their own individuality. (It is to be noticed that the presence of so-called pebble forms is the chief point urged for considering the granite as altered sediments.) When fusion has gone so far as to allow a complete interchange of material between the various parts of the rock and an entire obliteration of all differences in composition between its various parts, and when such a rock is allowed to cool and crystallize as a holocrystalline mass, it is but a simple disagreement in terms that cause such a mass to be called anything but a truly igneous rock; and if such a mass is moved from its original position and forced into other rock it is truly eruptive in its nature and origin.

It is not necessary here to consider the question concerning the origin of granites in general; that question is almost as old as geology itself; it dates from the times of Werner and Hutton, and the writer can not presume to discuss it. Nor is it necessary to say anything for or against the idea that some of the pre-Cambrian granites and granitoid gneisses may represent fused portions of ancient and very deeply buried rocks. But it can be stated that there seems to be abundant evidence that the Kekequabic granite shows no indication that it is an

altered sediment, that it is not part of the clastics of the region altered *in situ*, but that it is truly eruptive in its origin and nature, that it has broken through the surrounding rocks in a truly eruptive manner, and that throughout its whole extent now exposed to us it is sharply separated from the surrounding clastics and is of later date than these.

It might be well to state that when the writer began the study of this granite area and two others in northeastern Minnesota he was inclined to the view that these granites were the altered clastics of the region, but even before the field work was completed and before the microscopic study of the rocks was begun, he was forced to abandon this idea.

CHAPTER IV.

THE HORNBLENDE PORPHYRYTE.

The field relations of this rock have as yet been only partially studied, and the extent of the surface occupied by it has not been very accurately defined. For these reasons no complete discussion of this rock is now possible, and the time available in the preparation of this paper does not allow of a very detailed petrographical description, although quite a complete set of specimens showing the different phases of the rock have been collected.

The porphyryte is known from only one locality in the area studied, and is confined to a belt of not more than a quarter of a mile in width which curves around the southwestern end of Epsilon lake. The surface covered by this rock is about one-fourth of a square mile in extent; it is confined, with the exception of a few acres in the S. W. ¼ of S. E. ¼ section 20, to the N. ½ section 29, T. 65 N., R. 6 W. However a sample of this rock is noted by N. H. Winchell from Mallmann's peak*, which is on the north side of Kekequabic lake in the S. E. ¼ of section 30, T. 65 N., R. 6 W. The writer has been unable to find any porphyryte *in situ* at this place, and has since learned that Prof. Winchell did not visit Mallmann's peak personally, but that the specimen was brought to him by one of his guides. It is, however, quite possible that other areas of porphyryite will be found in sections 29 and 30, T. 65 N., R. 6 W., between Kekequabic and Knife lakes. The single specimen noted by Prof. Winchell has been figured and described microscopically by M. E. Wadsworth†.

The porphyryte has also been briefly described by A. Winchell,‡ who called it a purple porphyry, in his account of the geology of Epsilon lake.

*Geol. and Nat. Hist. Surv. of Minn., 10th (1881) Ann. Rept., pp. 92-93, 1882. Rock No. 751.

†Ibid., Bull. No. 2, pp. 124-125, pl. x, figs. 1 and 2, 1887.

‡Ibid., 16th (1887) Ann. Rept., pp. 321-327, 1888.

Dr. Wadsworth's description is as follows: "The section has a greenish gray groundmass, holding yellowish brown crystals of hornblende, epidote and greenish pseudomorphs of chlorite. The hornblende is of the usual foreign character in the andesitic rocks, having been attacked by the molten magma, which has torn and eaten into the hornblende, that has its edges blackened and rendered magnetic by the heating and corroding effects. Some of the hornblendes here have been broken and faulted, and blackened on the broken sides, others retain only a small portion of hornblende in the interior, while others are reduced to a heap of opacite or magnetite grains. The chlorite pseudomorphs are composed of plates and scales of chlorite with some epidote, but whether they are pseudomorphs after hornblende or augite the writer can not determine. The epidote is in small crystals and crystal aggregations of a pale yellowish color, with pleochroism varying from colorless to a pale yellow and to a deeper yellow. The epidote is here an alteration product, and is commonly associated with the chlorite. The groundmass is altered and is now composed of chlorite scales, partially altered augite microlites and granules, magnitite grains (disseminated through the entire groundmass), feldspar, microlites, fibrous material, etc., all replacing the usual felty base of the andesytes with its inclosed materials. Here the augite, feldspar and magnetite are original, and the rest secondary. * * * The rock itself is an altered and old andesyte of the variety known as porphyryte or hornblende-porphyryte amongst lithologists. This andesyte, in its original condition, would be called by most lithologists a hornblende andesyte." *

The single section, which was accessible to Dr. Wadsworth when his description was written, is more or less altered and does not clearly show the original nature of the groundmass. Other sections of the less altered rock show that the groundmass is composed of interlocking laths of feldspar,—sometimes the feldspar has a tendency towards a granular development,—as stated below.

Macroscopically the porphyryte is seen to have an aphanitic groundmass, which varies in color from a reddish purple to a dull olive green; the freshest and more abundant phases show the purple color. In this groundmass are sharply outlined shining black crystals of hornblende and also irregular greenish areas, in and around which are frequently small bright yel-

*Ibid., Bull. No. 2, pp. 124-125.

low spots and small white spots. Under the microscope the groundmass is seen to be made up entirely of small short interlacing laths of feldspar. In some sections the groundmass becomes coarser and there is a decided tendency towards a granular development of the feldspar. Although polysynthetic trimming is common, still some of the feldspar does not show it and seems to be monoclinic in character; that there is considerable orthoclase in the rock is also indicated by the percentage of potash in the analysis.* The feldspar is undergoing alteration and is filled with small inclusions and minute fibers which sometimes appear to be sericite. The rock is crowded with dust-like particles, to which perhaps is due its purple color. There seems to have been but one period of crystallization for the feldspar, phenocrysts of this mineral being entirely absent. In all the slides examined there is no unindividualized glassy matter to be seen.

The hornblende is of the usual brown basaltic variety, but the pleochroism is not as intense as in most basaltic hornblendes; $\mathfrak{a}$ is light straw colored, $\mathfrak{b}$ is yellowish brown and $\mathfrak{c}$ is olive brown. The rays vibrating parallel to $\mathfrak{b}$ and $\mathfrak{c}$ are not very unlike. The absorption formula is $\mathfrak{c}=\mathfrak{b}>>\mathfrak{a}$ or $\mathfrak{c}>\mathfrak{b}>>\mathfrak{a}$. The hornblende is all porphyritic in character, the individual crystals being from one to five millimeters in length. Each phenocryst is usually surrounded by a dark corrosion rim.

The dull greenish areas seen in hand specimens are found to be aggregates of chlorite scales, sometimes with a radial arrangment. It is evident that some of this chlorite is an alteration product of the hornblende. But most of the chlorite areas give no evidence as to their origin. In one section a core of pyroxene was seen in a chlorite area, and it is possible that many of these chlorite areas represent old augite phenocrysts; however, they do not show the characteristic outlines of augite crystals, but are usually irregular. Even if all of these chlorite areas, which are not clearly alteration products of hornblende crystals, represent original augite individuals, the hornblende would still be in excess of the augite. So the rock is called a hornblende porphyryte, although it perhaps originally was an augite-hornblende porphyryte.

*Dr. Whitman Cross, who kindly examined slides of this rock for the writer, also thinks that considerable orthoclase is present.

The yellow spots in and around the chlorite areas are secondary epidote, often in the form of minute spheres. And small white spots of calcite are also seen.

The analysis of the porphyryte is as follows:

SiO_2	Al_2O_3	P_2O_5	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	H_2O	Total.
60.32	15.80	0.12	5.42	0.89	4.65	5.08	1.82	4.09	1.67	99.86.

In the porphyryte have been seen a few fragments of rock similar to the graywacke of the region, and at its contact with the surrounding rock the former is finer grained than is usual, but it does not seem to have alterėd the rocks with which it comes in contact. It seems very probable that this mass of porphyryte is a part of the same magma which produced the volcanic tuff about Kekequabic lake, but that it solidified before reaching the surface, and at present we have no knowledge in this region of a surface flow of rock similar to the tuff.

EXPLANATION OF PLATES.

PLATE I.

Fig. 1. Cascade between Epsilon and Knife lakes.
Fig. 2. Pyroxene granite porphyry, with unusually large phenocrysts of feldspar. (No. 776 G.) Three-fourths natural size.

PLATE II.

Geological map of Kekequabic lake and vicinity, Lake Co., Minn. The figures in the lakes show their hight above sea level.

Fig. 1.

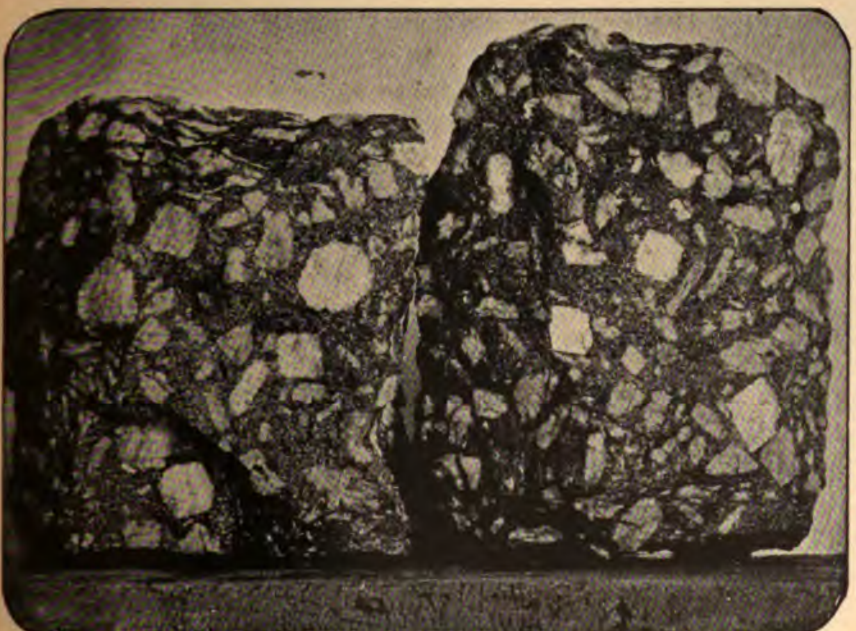


Fig. 2.

III

CATALOGUE OF ROCK SPECIMENS COLLECTED IN NORTHEASTERN MINNESOTA IN 1892

BY ULYSSES SHERMAN GRANT

This list is a continuation of that ending on page 110 of the 20th (1891) Annual Report. Most of the specimens have not been examined since they were collected, so the designations may not always be correct. The terms "greenstone" and "muscovado" are applied, according to the field usage of the Survey, to certain rocks which have not as yet been closely studied. In giving localities the township is always *north*, and the range is always *west* of the Fourth Principal meridian.

735. Muscovado near gabbro contact. S. E. ¼ S. E. ¼ S. W. ¼ sec. 32, T. 64–7, island in Thomas lake.

736. Coarse biotitic gabbro. S. ½ sec. 18, T. 64–6, north shore of Marble lake.

737. Muscovado. N. ½ N. W. ¼ sec. 7, T. 64–6.

738. Altered conglomerate. S. ½ S. W. ¼ sec. 6, T. 64–6.

739. Matrix of altered conglomerate. S. W. ¼ S. E. ¼ sec. 1, T. 64–7.

740. Matrix of altered conglomerate. N. W. ¼ N. E. ¼ sec. 12, T. 64–7.

741. Fine gabbro. N. ½ N. E. ¼ sec. 12, T. 64–7.

742. Metamorphosed matrix of altered conglomerate. N. W. ¼ N. W. ¼ sec. 7, T. 64–6.

743. Compact gray argillyte. E. ½ S. E. ¼ sec. 1, T. 64–7.

744. Greenstone band in altered slate. N. W. ¼ S. E ¼ sec. 1, T. 64–7.

745. Altered slate. Same locality.

746. Pyroxene granite near contact with slate. N. W. ¼ S. E ¼ sec, 1, T. 64–7.

747. Gray slate near granite contact. Same locality.

748. Pyroxene granite. N. W. ¼ S. E. ¼ sec. 1, T. 64–7.

749. Pyroxene granite near contact with slate. N. E. ¼ S. E. ¼ sec. 1, T. 64–7.

750. Feldspathic vein rock in slate. N. E. ¼ S. E. ¼ sec. 1, T. 64-7.

751. Hardened slate. Same locality.

752. Fine biotite rock. S. ½ N. W. ¼ sec. 12, T. 64–7, portage running northeast from Shoofly lake.

753. Vitreous quartzyte carrying more or less magnetite, near gabbro contact. N. ½ N. W. ¼ sec. 20, T. 64–6.

754. Gabbro near contact with quartzyte. Same locality.

755. Purple syenite. S. W. ¼ N. E. ¼ sec. 34, T. 63–6.

756. Diorite. Probably in the N. W. ¼ N. W. ¼ sec. 12, T. 62–6.

757. Very coarse gabbro. Probably in the N. E. ¼ S. W. ¼ sec. 12, T. 62–6, bay on north side of Syenite lake.

758. Brick red syenite. Probably in the S. W. ¼ sec. 12, T. 62–6, north side of Syenite lake.

759. Fine grained dark syenite. Probably near the centre of the N. ½ sec. 13, T. 62–6, east shore of Syenite lake.

760. Fine grained pinkish syenite. Probably near the centre of sec. 13, T. 62–6, east shore of Syenite lake.

761. Fine grained pinkish syenite. Probably in the N. W. ¼ sec. 24, T. 62–6, southeast shore of Syenite lake.

762. Fine grained gray syenite. Probably in the S. W. ¼ sec. 24, T. 62–6, southeast shore of Syenite lake.

763. Fine grained gray syenite. Probably in the S. W. ¼ sec. 12, T. 62–6, island in north part of Syenite lake.

764. Volcanic tuff. N. E. ¼ S. E. ¼ sec. 34, T. 65–7, island in Kekequabic lake.

765. Dark slate near contact with pyroxene granite porphyry. E. ½ S. W. ¼ sec. 34, T. 65–7, point on north side of Kekequabic lake.

766. Dark slate and pyroxene granite porphyry in contact. Same locality.

767. Green schist. N. E. ¼ S. W. ¼ sec. 35, T. 65–7, island near north shore of Kekequabic lake.

768. Greenish graywacke. S. W. ¼ N. E. ¼ sec. 33, T. 65–7, bay on north side of Plum lake.

769. Compact carbonate rock. N. E. ¼ S. W. ¼ sec. 33, T. 65–7, west end of Plum lake.

770. Volcanic tuff. N. E. ¼ sec. 35, T. 65–7, top of hill on north side of Kekequabic lake.

771A to 771F. Pyroxene granite from an exposure which is broken into parallel sheets. S. E. ¼ S. W. ¼ sec. 2, T. 64–7, west side of point on south shore of Kekequabic lake.

772. Interbanded green slate and dark red jaspilyte. Near center of N. W. ¼ sec. 35, T. 65–7, southeast corner of Pickle lake.

773. Medium grained diabase. N. W. ¼ S. E. ¼ sec. 26, T. 65–7, south shore of Spoon lake.

774. Pyroxene granite. N. E. ¼ sec. 1, T. 64–7, summit of ridge south of Kekequabic lake.

775. Coarse diabase. S. E. ¼ S. W. ¼ sec. 29, T. 65–6, top of hill on north shore of Kekequabic lake.

776. Pyroxene granite porphyry with large feldspar phenocrysts. N. W. ¼ S. W. ¼ sec. 31, T. 65–7, just south of Kekequabic lake.

776A. Pyroxene granite within three inches of porphyry contact. Same locality.

777. Pyroxene granite. Same locality.

777A. Pyroxene granite porphyry within six inches of granite contact. Same locality.

778. Granite and granite porphyry in contact. Same locality.

778A. Altered argillyte. S. E. ¼ S. W. ¼ sec. 31, T. 65–6, south of Kekequabic lake.

778B. Argillyte. Same locality.

779. Pyroxene granite. Same locality.

779A. Pyroxene granite with dark feldspars. Same locality.

780. Sericitic argillyte. Same locality.

781. Hornblende granite (?). N. E. ¼ S. W. ¼ section 31, T. 65–6, just south of Kekequabic lake.

782. Pyroxene granite. Same locality.

783. Hornblende granite (?). Near center of section 31, T. 65–6, just south of Kekequabic lake.

783A. Rock fragments from same. Same locality.

784A and 784B. Altered grit. Probably near center of E. ½ section 32, T. 65–6.

785. Altered grit with red jaspilyte fragments. Probably in S. E. ¼ section 32, T. 65–7, east shore of small lake.

786. Pyroxene granite porphyry. Same locality.

787. Conglomerate. S. W. ¼ N. W. ¼ section 31, T. 65–6, south shore of Kekequabic lake.

788. Pyroxene granite porphyry near graywacke (?). S. W. ¼ S. W. ¼ section 29, T. 65–6, north shore of Kekequabic lake.

788A to 788C. Rock intermediate between 788 and 788D. Same locality.

788D. Graywacke (?). Same locality.

789. Porphyritic metamorphosed conglomerate. S. W. ¼ N. E. ¼ section 28, T. 65–6, north side of narrows of Zeta lake.

790. Gabbro near contact with quartzyte. N. E. ¼ N. E. ¼ section 34, T. 65–5.

791. Muscovado. N. E. ¼ N. E. ¼ section 34, T. 65–5, north side of stream.

792. Grayish purple hornblende porphyryte. North line of section 29, T. 65–6, south shore of Epsilon lake.

793 and 793A. Purple hornblende porphyryte. N. W. ¼ N. E. ¼ sec. 29, T. 65-6, hill on shore of Epsilon lake.

793B. Decayed dolomyte (?). S. E. ¼ S. W. ¼ sec. 20, T. 65-6, west shore of Epsilon lake.

794. Green porphyryte at contact with slate. S. W. ¼ S. E. ¼ sec. 20, T. 65-6, west side of little bay on south shore of Epsilon lake.

794A. Porphyryte near contact with slate. Same locality.

794B. Greenish slate at porphyryte contact. Same locality.

795. Graywacke from inclusion in porphyryte. S. E. ¼ N. W. ¼ sec. 29, T. 65-6, between Epsilon and Beta lakes.

796. Green porphyryte near contact with slate. Same locality.

797. Typical purple hornblende porphyryte. N. E. ¼ S. E. ¼ N. W. ¼ sec. 29, T. 65-6, south end of Epsilon lake.

798. Coarse diabase from centre of large dyke. Near south line of sec. 20, T. 65–6, between Epsilon and Knife lakes.

798A. Fine diabase from small dyke. Same locality.

799. Coarse diabase. Near centre of N. ½ sec. 7, T. 65-6, northwest corner of Amœba lake, at the portage.

800. Flinty black slate showing lamination. N. W. ¼ S. E. ¼ N. E. ¼ sec. 7, T. 65-6, north shore of Amœba lake.

801. Coarse grit holding black fragments. S. E. ¼ N. E. ¼ sec. 7, T. 65-6, north shore of Amœba lake.

801A. Black fragments from same. Same locality.

802. Fine grained laminated graywacke. N. E. ¼ S. E. ¼ sec. 7, T. 65-6, island in Amœba lake.

803. Flinty slate showing conchoidal fracture. N. E. ¼ N. E. ¼ sec. 18, T. 65-6, west side of bay of Amœba lake.

804. Carbonaceous (?) slate. N. W. ¼ N. E. ¼ sec. 8, T. 65-6, east shore of small bay.

805. Volcanic tuff (?). Near north line of sec. 9, T. 65-6, southeast shore of lake.

806. Greenish tuff (?) graywacke. W. ½ N. E. ¼ sec. 9, T. 65-6, south east shore of lake.

807. Green volcanic ash (?). N. E. ¼ S. W. ¼ sec. 3, T. 65-6, west shore of lake.

808. Greenish slate and graywacke showing lamination. Same locality.

809 A and 809 B. Gray argillyte. N. W. ¼ N. W. ¼ sec. 2, T. 65-6, east side of lake.

810. Coarse graywacke. N. E. ¼ S. E. ¼ sec. 3, T. 65-6, south end of island.

811. Breccia. S. E. ¼ N. W. ¼ sec. 10, T. 65-6, near north end of portage.

812. Green volcanic ash (?). S. E. ¼ S. W. ¼ sec. 3, T. 65-6, west shore of lake.

812 A. Green schist. S. ½ N. E. ¼ sec. 2, T. 65-6, north shore of lake.

813. Grit. S. W. ¼ sec. 1, T. 65-6.

814. Conglomerate. N. W. ¼ N. W. ¼ sec. 1, T. 65-6, west shore of lake.

814 A. Coarse hornblende granite from boulder in the conglomerate. Same locality.

814 B. Various pebbles from the conglomerate. Same locality.

814 C. Green pebbles from the conglomerate. E. ½ S. E. ¼ sec. 35, T. 66-6, west shore of lake.

815. Peculiar light gray graywacke. S. ½ S. W. ¼ sec. 10, T. 65-6, north shore of Knife lake at portage.

816. Breccia. N. W. ¼ S. W. ¼ sec. 10, T. 65-6, top of steep hill.

817. Conglomerate. N. E. ¼ N. E. ¼ sec. 10, T. 65 6.

817 A. Pebbles from conglomerate. Same locality.

817 B. Variolyte (?) pebbles from conglomerate. Same locality.

818. Coarse grit showing sub-porphyrytic white feldspars. E. ½ S. E. ¼ N. E. ¼ sec. 34, T. 66-6, west side of point in lake Avis.

819. The same. S. W. ¼ N. W. ¼ N. W. ¼ sec. 35, T. 66-6, point on west shore of lake Avis.

820. Coarse grit holding elongated gray pebbles. N. W. ¼ N. E. ¼ sec. 34, T. 66-6, point on north shore of lake.

821 and 821A. Contact of Ogishke conglomerate and granite. N. E. ¼ S. E. ¼ sec. 7, T. 65-5, west of West Sea Gull lake.

822. Greenstone. Near centre of S. E. ¼ sec. 7, T. 65-5, west of West Sea Gull lake.

823. Dark green schist. N. line of sec. 22, T. 65-5, a short distance E. of the N. W. corner of the section.

824. Gray porphyrytic rock. A short distance E. of the last.

825. Pink granite. N. line of sec. 22, T. 65-5, ⅛ mi. E. of the N. W. corner of the section.

826. Granite. A short distance E. of the last.

827. Chloritic granite. N. line of sec. 22, T. 65-5, E. of the ¼ post.

827 A and 827 B. Quartz-porphyry (?). Same locality.

828. Granite in contact with greenstone. E. line of sec. 23, T. 65-5, about ¼ mi. N. of the ¼ post.

829 and 829 A. Greenstone near granite contact. Same locality.

829 B. Greenstone holding a few quartz grains. A short distance S. of the last.

829 C. Greenstone. E. line of sec. 23, T. 65-5, about ⅛ mi. N. of the ¼ post; top of high ridge.

829 D. Very coarse greenstone. Same locality.

829 E. Coarse greenstone. E. line of sec. 23, T. 65-5, at the ¼ post.

830. Greenstone containing purple areas. W. line of sec. 23, T. 65-5, S. of the ¼ post.

831. Fine grained syenite. Same locality.

832. Light purplish graywacke. Same locality.

833. Gray porphyritic rock. W. line of sec. 26, T. 65-5, a short distance S. of the N. W. corner of the section.

834. Greenstone with hornblende crystals and pebble forms. W. line of sec. 26, T. 65-5, N. of the ¼ post.

835. Grit. S. line of sec. 21, T. 65-5, W. of the ¼ post.

836. Diabase. N. line of sec. 21, T. 65-5, W. of the ¼ post.

837. Altered camptonyte (?). S. W. ¼ N. W. ¼ sec. 12, T. 65-5, N. W. shore of Cucumber island, Sea Gull lake.

838. Greenstone. N. W. ¼ sec. 20, T. 65-5.

839. Granite with vein of chalcedonic (?) silica. [See: "Geological age of the Saganaga syenite", by H. V. Winchell; Amer.

Jour. Sci., vol. xli., pp. 386–390, May, 1891.] This specimen is from the vein described in this article. N. E. ¼ S. W. ¼ sec. 12, T. 65–4, Granite river, at east end of portage.

840. Greenstone. Sec. 1, T. 64–6, west shore of Gabimichigama lake.

840A. Greenstone holding magnetite. S. W. ¼ S. E. ¼ sec. 1, T. 64–6, west shore of Gabimichigama lake.

841. Coarse gabbro. S. W. ¼ S. W. ¼ sec. 1, T. 64-6, west end of Gabimichigama lake.

841A. Coarse biotite muscovado. S ½ S. W. ¼ sec. 1, T. 64–6, north side of bay of Gabimichigama lake.

842. Diabase from centre of dyke. N. ½ N. ½ sec 12, T. 64–6, north side of point in Gabimichigama lake.

842A. Fine diabase from edge of dyke, with gabbro attached. Same locality.

843. Fine gabbro (?). S. E. ¼ S. E ¼ sec. 1, T. 64–6, north side of small bay of Gabimichigama lake.

844. Heavy, dark, biotitic band in the quartzyte. S. W. ¼ S. E. ¼ section 1, T. 64–6, east shore of Gabimichigama lake.

845. Light gray muscovado. N. ½ S. W. ¼ section 1, T. 64–6, south shore of Gabimichigama lake.

845A. Yellow muscovado. Same locality.

846. Quartzyte with magnetite and much amphibole. Near line between ranges 6 and 7, T. 64, south shore of Gabimichigama lake.

847. Muscovado from fragment in gabbro. S. W. ¼ N. W. ¼ section 6, T. 64–5, island in Gabimichigama lake.

848. Pyroxene from gabbro. S. E. ¼ S. W. ¼ section 32, T. 65–5, east shore of Gabimichigama lake.

849. Red granite from vein in gabbro. N. W. ¼ N. E. ¼ section 6, T. 64–5, island in Gabimichigama lake.

850. Muscovado from the gabbro. S. W. ¼ S. W. ¼ section 1, T. 64–6.

851. Gabbro consisting almost entirely of plagioclase. S. E. ¼ N. E. ¼ section 16, T. 64–5, east shore of Little Saganaga lake.

852. Fine granite from dyke in gabbro. E. ½ section 16, T. 64–5, east shore of Little Saganaga lake.

853. Diabase from dyke in gabbro. N. E. ¼ N. E. ¼ section 24, T. 64–6, portage leading southwest from Little Saganaga lake.

854. Quartz gabbro. S. E. ¼ S. W. ¼ section 12, T. 64–6, southwest shore of small lake.

854A. Coarse grained quartz gabbro. Same locality.

855. Muscovado. W. line of section 9, T. 64–5, a short distance from the N. W. corner of the section.

856. Muscovado. N. W. ¼ S. E. ¼ section 22, T. 64–5.

857. Typical fresh muscovado. The large faces of the specimen are parallel to the "bedding". Near line between sec. 2, T. 64-5 and sec. 35, T. 65-5, northeast shore of bay of Bashitanakueb lake.

857A. Typical fresh muscovado. A few rods north of the last.

857B. Decaying muscovado. The large faces of the specimen are parallel to the "bedding". Same locality.

858. Olivine gabbro showing a gneissic structure. N. E. ¼ N. W. ¼ sec. 11, T. 64-5, south shore of Bashitanakueb lake.

859. Olivine gabbro. N. ½ S. E. ¼ sec. 3, T. 64-5, north shore of Bashitanakueb lake.

859A. Nodules rich in olivine and magnetite, from the gabbro. Same locality.

860. Rather coarse grained fresh muscovado. S. W. ¼ S. E. ¼ S. W. ¼ sec. 36, T. 65-5, south shore of Muscovado lake.

861. Reddish granite. N. E. ¼ S. W. ¼ sec. 3, T 64-5, south shore of lake.

862. Quartzyte showing fine laminæ. N. ½ sec. 34, T. 65-5.

863. Muscovado showing banding. N. ½ sec. 2, T. 64-5.

864. Green schist. S. side of S. E. ¼ S. E. ¼ sec. 21, T. 65-4.

864A. Fine grained quartzyte band. Same locality.

864B. Magnetite band. Same locality.

865. Fine grained greenstone. N. E. ¼ S. E. ¼ section 24, T. 65-5, south shore of lake.

865A. Greenstone at contact with syenite porphyry. S. E. corner of N. E. ¼ S. W. ¼ sec. 24, T. 65-5.

866. Syenite porphyry. Same locality.

866A. Syenite porphyry at contact with greenstone. Same locality.

867. Greenstone. W. ½ S. W. ¼ sec. 30, T. 65-4, portage east from Flying Cloud lake.

868. Greenstone. N. W. ¼ S. W. ¼ sec. 30, T. 65–4, north shore of lake.

869. Coarse mottled greenstone. S. W. ¼ N. W. ¼ sec. 30, T. 65–4, north end of portage.

870. Schistose greenstone. The large flat surface is parallel to the schistose structure. S. E. ¼ N. W. ¼ sec. 30, T. 65–4, south side of lake.

871. Gabbro ten feet from contact. N. E. ¼ N. E. ¼ S. E. ¼ sec. 30, T. 65-4, south shore of stream.

871A. Gabbro within eighteen inches of contact. Same locality.

871B. Gabbro within two inches of contact. Same locality.

872. Gray biotite rock. Near north line of sec. 31, T. 65-4, west side of Gaiter lake.

873. Fine gabbro within 100 feet of contact with quartzyte. W. ½ N. W. ¼ S. W. ¼ sec. 29, T. 65-4.

874. Porphyritic diabase. S. W. ¼ N. E. ¼ sec. 29, T. 65-4, just north of Akeley lake.

874A. Diabase from contact at top of sheet. Same locality.

874B. Diabase from contact at bottom of sheet. Same locality.

874C. Quartzyte at contact with diabase. Same locality.

875. Greenstone. S. W. ¼ N. E. ¼ sec. 29, T. 65-4, just north of the workings at Akeley lake.

876. Gray rock holding graphite. S. W. ¼ N. E. ¼ sec. 28, T. 65-4, Paulson's camp.

876A. The same at gabbro contact. Same locality.

877. Fine grained gray quartzyte. E. ½ S. W. ¼ sec. 21, T. 65-4.

878. Greenstone. Same locality.

879. Fine quartzyte banded with magnetite. Same locality.

880. Magnetitic iron ore. Near center of N. ½ sec. 28, T. 65-4.

881. Coarse vitreous quartzyte. S. W. ¼ N. W. ¼ sec. 28, T. 65-4.

882. Peculiar dark micaceous part of quartzyte. N. ½ S. W. ¼ N. E. ¼ sec. 28, T. 65-4.

883. Gabbro. E. line of sec. 27, T. 65-4, north of the ¼ post.

884. Fine gabbro. S. E. ¼ N. E. ¼ sec. 29, T. 65-4.

885. Coarse olivine gabbro. S. W. ¼ N. E. ¼ sec. 28, T. 65-4, south shore of small lake.

885 A. Gabbro very rich in olivine. Same locality.

886. Fine diabase. S. E. ¼ S. E. ¼ sec. 22, T. 65-4.

887. Nickel ore. S. W. ¼ N. W. ¼ N. W. ¼ sec. 27, T. 65-4.

888. Garnetiferous band in green slates. Just N. of the S ¼ post of sec. 22, T. 65-4.

889. Diabase from dyke. Just S. of the N. E. corner of sec. 22, T. 65-4.

889 A. Fine diabase from edge of dyke. Same locality.

890. Gray quartzyte. About ¼ mi. S. of the N. E. corner of sec. 22, T. 65-4.

891. Porphyritic diabase. S. E. ¼ S. E. ¼ sec. 22, T. 65-4.

892. Gray quartzyte band from the slates. Same locality.

893. Diabase from dyke. Cross river, S. line of sec 27, T. 65-4.

IV.

PRELIMINARY REPORT OF A RECONNOISANCE IN NORTHWESTERN MINNESOTA IN 1892.

BY J. E. TODD.

ITINERARY.

Having prepared an outfit, consisting of a covered spring wagon and span of ponies, and secured an experienced assistant, Mr. Arthur W. Chase of Hastings, I left Minneapolis July 7, 1892.

We proceeded by the main road, up the west bank of the Mississippi to Little Falls, there crossed and continued on the opposite side to Brainerd, arriving July 12th.

Pursuant to correspondence with Mr. S. A. Shellabarger and Mr. Pettengill, both of Staples, I went by rail to that point. I there investigated reported finds of petroleum, found them mistaken, and with the latter gentleman visited some "curious mounds," on sections 9 and 16, T. 132, 33; they were clearly an "osar" half a mile long and 30 to 50 feet high.

Returning to Brainerd, I prepared for camping, and proceeded to Leech lake by the main trail, via. Pine River and Hackensack post offices. Of necessity I returned to the latter point, sec. 19, T. 140, 30, and thence went nearly due west to Park Rapids. Thence northwest to the county line which we followed quite closely to lake Itasca, then down its east side to its outlet, where we procured a boat and visited the southwest head of the lake and photographed its inlets and Elk lake.

From Itasca we kept a north course, fording the Mississippi at Dutch Fred's crossing, on to Mike Spain's, sec. 29, 146, 35. After making a short trip about three miles northwest, we followed the trail to lake Bemidgi, crossing the Little Mississippi on sec. 16, 146, 35, Grant creek on or near sec. 29, 147, 34, and lake Bemidgi upon the circular bar formed by the inflowing Mississippi. From Carson's trading post on the south

shore of the lake, we retraced our course six or seven miles, then struck north by a trail to N. E. cor. sec. 26, 148, 34, and thence a little south of west to Bagley Dam, sec. 31, 148, 35, on Clearwater river.

After taking a foot-trip about six miles southwest from there, nearly to the Little Mississippi, we went on down the west bank of the Clearwater to Clearwater Lake dam, sec. 12, 149, 36. Thence we made a trip to Red Lake Agency, going by the "Little Rock road" and returning by the "Sugar Camp road." The two coincide as far as Sandy river. A foot trip was also taken about two miles south from the Agency. We reached the Agency July 28. After returning to Clearwater lake dam we took the old trail to Fosston via. How's, sec. 4, 147, 37, and Popple, sec. 22, 147, 38.

From Fosston we went on past McIntosh, "Bucktown," Lambert and Badger, west to sec. 1, T. 150, 45, thence south two miles, then east and north to Red Lake Falls. Thence to Thief River Falls, where finding that we could not take a short course to Jadis, we went by Excel and Bokke's, sec. 22, 156, 45, to the "Pembina trail," crossed Middle river near the S. E. corner of T. 157, 46, and the Tamarac near the middle of the north line of the same, we soon got on to the "Jadis ridge" which we followed over 40 miles nearly to that point. From Jadis we took our team to sec. 15, T. 162, 39, where we left it and taking a guide made our way on foot to the mouth of War Road river on Lake of the Woods, arriving Aug. 9th. Next day we hired an Indian with his canoe to take us past Rocky point and two or three miles northeast to a bare, rocky island which for convenience we will call Cormorant island because we found a score or more of cormorant nests upon it.

From this our farthest point we retraced our former course as far as the Tamarac river, at Nelson's, sec. 14, 158, 46, because there was no other practicable. From that point we went to Stephen by the stage route, and from there southeast to a road running east from Argyle, which we followed past Bokke's, Humboldt, Ingalls and Breese postoffices to sec. 11, T. 157, 42, where I left my team, and went on foot five or six miles east over marshy ground to the southern side of Thief lake. We then proceeded directly past Holt and Excel postoffices, Thief River Falls, St. Hilaire, Red Lake Falls and Lambert, to sec. 19, T. 150, 40; thence south about four miles, whence several short trips were taken on foot to explore an old channel, and thence southeast to Fosston.

From that point by the usual trail to White Earth Agency and on south past Richwood to Detroit, where I took the train for Minneapolis, Aug. 27th, leaving Mr. Chase to bring on the team.

SKETCH OF OBSERVATIONS AND RESULTS.

I was furnished with aneroid, compass, field glass and camera. Opportunity for extensive views were rare and over much of the way departure from the regular trail very laborious, and, therefore, seldom attempted. Opportunities for interviewing old settlers, surveyors and "cruisers," were diligently sought, and frequently led to valuable information.

1. *Exposures of Older Rocks.*—North of Little Falls no exposure of "bed-rock" anywhere was found except at the extreme limit of our journey, in Lake of the Woods. At Rocky point, showing nearly a mile along its west side and extending I was told several miles east, finely glaciated knobs rose like whale-backs 5 to 15 feet above the water level. Cormorant island, covering perhaps half an acre and rising 15 feet above the water, and a few small islands south of it were composed entirely of such rocks eroded a very little by the lake. The level of the lake was about six feet higher than a short time before because of a dam placed across its outlet at Rat Portage, as I was informed.

The rock at Cormorant island and the northern part of Rocky point is a dark magnetic gabbro as it would appear on macroscopic examination. It was found so highly magnetic that no reliance could be placed on the compass. The needle would swing all round the circle within a few feet if held three or four feet above the surface of the rock, and a mass of about a dozen cubic inches would hold the needle placed by it, in any position.

This rock is in places coarse grained and porphyritic. Upon Cormorant island it exhibited a striped appearance of flowing lines of light and dark, shading into one another.

Joining this dark rock upon the southwest is a fine grained pinkish gray granite, the intersecting plane between them being nearly perpendicular.

I met at Red lake a settler by the name of Wm. Kasson who told me that there was an exposure of dark hard rock, rising a few feet above the south fork of Battle river, on or near sec. 36, 152, 30.

Another settler who had been a quarryman said that ten miles west of where Badger creek enters the "Big muskeg," near the center of Kittson county, he dug down four feet below the surface and found limestone four feet square without seams, how much more extensive he did not discover. Not far away on a ridge he saw flaky layers of limestone, tipped.

At Red Lake Falls a well had been bored over 400 feet. From the statements of the borer, Mr. Anderson, the following section is made;

1. 47 ft. Lacustrine clay, much of it laminated.

2. 47-112 feet. Clay with small stones. Water struck in limited quantity at 47 feet.

3. 112-316 feet. Sand and gravel cemented above the water for several feet.

Struck water at 118 feet and 316. The last rose up to 47 feet.

4. 316-407. Clay without grit. Could bore 50 feet a day.

No. 4 is without doubt preglacial and possibly part of No. 3.

Mr. J. C. O'Brien of Red Lake Falls informed me that there are rock-ledges along most of the course of Rainy river; that Rapid river, which is a large stream, has a branch running nearly parallel with Rainy river, and not far away from it, skirting the edge of the rocky area.

2. *Glacial Drift.*—This formation covers without doubt the whole region visited, with the exceptions already mentioned. It is in turn covered over wide areas by more recent deposits formed by lakes and rivers.

As regards the characters of the drift sheet in general, little need be said here. The upper or modified drift, which may be the enclacial drift more or less stratified by the waters of the melting ice-sheet, is generally sandy in the Mississippi basin and over the divide toward the Red Lake as far as the morainic strip running east south of the lake. A clayey strip was noticed south of Leech lake and another extending northeast—southwest crossing T. 148, 35. In this same area limestone erratics are very rare. Dr. Jas. R. Walker, sub-agent at Leech lake, after wide travel informed me that he had seen but one limestone boulder. I found none until I reached T. 146, 36, and then only one or two small shaly ones. I found a few lime-pebbles in lake Itasca. Throughout this same area black silicious slaty boulders seem more common than elsewhere.

After entering the morainic strip south of Clearwater lake, limestone boulders became more abundant and were not very

scarce throughout the rest of our journey. In the rest of our course also, clay was the common subsoil, except on terraces and beaches. It was generally of a light gray, though sometimes yellowish.

Typical till was observed at the base of several high banks along the Clearwater and Red Lake rivers.

Moraines.—Not venturing to decide their relations, in most cases, I will simply enumerate them by localities.

(*a*). Rough ground was struck southeast of Gull lake, and continued more prominently west of the lake north to a little north of Twin lakes. High ground was crossed just south of Pine river in T. 137, 29. This apparently came in from the southwest, and was thought to connect with the ridges left 8 or 10 miles further south.

(*b*). A very rough country was entered in the northwest corner of T. 139, 30, and traversed for about 14 miles going north. It rose 150 to 175 feet above Leech lake and 80 to 100 above the country south. Dr. Walker informed me that it did not extend farther east than the southeast corner of Leech lake, also that there were hills southwest of the lake. I was informed by a "cruiser" that there were hills west of Pine lake which connected with those along Gull lake, therefore I am disposed to consider the morainic region south of Leech lake to be an interlobular angle of the same moraine to which (*a*) belongs.

(*c*). No distinct morainic features were noticed between Hackensack and Park Rapids, but near the southeast corner of T. 141, 36, we encountered ridges again, extending east and west, which became higher and rougher northward. These features continued till we were east of the fork in lake Itasca. Its higher points rise 150 feet or more above the lake.

(*d*). Along Grant creek in T. 147, 34, we encountered a narrow but well defined moraine running S. S. E., the knobs rising abruptly 25 and 30 feet. A trader, Mr. Carson, of lake Bemidgi, said it passed 4 or 5 miles south of that lake. We crossed an elevated strip in the south part of T. 148, 34, which is supposed to be a continuation of the same, running more directly north. From reports we judge that it joins a morainic strip running east and west, a little further north.

(*e*). A clayey elevated undulating strip was crossed in the northern part of T. 148, 35, crossing the Clearwater in an eastward direction, and rising in places 175 feet above that stream.

(*f*). The region north and west of Clearwater lake is morainic, and east of the crossing of Sandy river there are knobs rising 125 feet above that stream and 50 feet above the clayey plain north. This is believed to be the northern member of a double or interlobular moraine running east. Its northern slope is understood to extend quite directly westward through the southern part of T. 150, 40.

(*g*). The region traversed between Clearwater lake dam and Fosston was mostly morainic, higher points being crossed in 148, 36, near the east line of 147, 38, and near center of 147,39. There appears to be a moraine running southwest along northwest of the upper Clearwater, which very likely connects with the eastern morainic belt in Becker county.

(*h*). The country is morainic north and northwest of Fosston, but not so distinctly so west and south, though there are some knobs along west of the old valley leading east and south of that place.

(*i*). A very stony well defined moraine crosses the southern tier of sections in T. 150, 40, and ends abruptly near the southwest corner, where it crosses a well preserved lake beach. This is believed from reports to connect with (*f*.)

(*j*). A well developed moraine was crossed south of the Wild Rice river in T. 144, 40, where it rises over 100 feet above that stream. The same moraine was seen on the lower land, in or near T. 143, 43. I refrain from speaking of moraines already noted in reports.

(*k*). Mild morainic features were noted along west of the south courses of Thief and Red Lake rivers, in range 44, in north Polk county, particularly a few miles south of St. Hilaire. There are shallow basins separated with narrow low ridges and frequent boulders in places. It has evidently been subject to lacustrine action also. This is thought to continue southeast from 152, 44 and connect with (*i*).

(*l*). Five or six miles southwest of the mouth of War Road river we passed over a ridge lying east and west, about 45 feet in hight above the peat marshes or "muskegs" around. It was quite sandy in places, but showed boulders at various points and one circular basin was noted toward the east end. It was impossible to get a good idea of its form on account of the trees, but it appeared like an inclined sand plain sloping southward. Two other low bouldery ridges were crossed southwest of it. Mr. G. F. Schoonover, our guide, said that a similar ridge corresponding to the first mentioned was found farther

east and connected with a ridge running nearly southwest from Rocky point. There is said to be a ridge a little north of the boundary, called Pine ridge, which connects north with White-mouth ridge, just how I could not make out. High land north of the Roseau can be seen from Jadis ridge.

Rumors have come to me from several sources, some of them quite circumstantial, that there is quite a high ridge south or southwest of Rocky point. Possibly these may be morainic ridges to be correlated with (*i*) and (*k*). They are probably more or less shaped by lacustrine action.

Osars.—In or near the southeast corner of T. 146, 36, I ascended the head of an abrupt ridge rising about 100 feet above the surrounding plain. Its train of knobs of diminishing hight trended S. 30° W. mag. It was quite bouldery.

Some low winding ridges trending eastward were noted in the valley a few miles south of Fosston, which were probably of this class. They were not over 20 feet in hight.

In regions already described I noted two fine examples. One on sections 9 and 16, 132, 33, already mentioned, and one not far from Darling, Morrison Co. It is cut by the railroad and exhibits the stratified structure finely. It is 30 or 40 feet high.

Pitted Plains.—I know of no better term to express what I have observed at several points, though I am not sure that what have been so called by others are the same.

The finest example of this class is found south and southwest of Red lake. The topography is very even, rising gently to the south, but dotted with basins with abrupt sides and of quite uniform depth. These depressions are of all sizes from a few feet across to many acres. I could not resist the impression that an ice-sheet had gone to pieces, its blocks stranded and clay and sand had filled in quite level around them. Later they had melted and left their places vacant.

A similar but less perfect example is found about Leech lake and north of the east course of the Mississippi. Along the Little Mississippi this structure was marked along its channel, as though a subglacial channel had been marked by blocks of ice. This was noted particularly in the western part of 146.35.

Old Channels.—Only a few of the more significant need be mentioned.

(*a*). There is a conspicuous gap through Moraine (*i*), beginning on or near sec. 27, 150, 40. From it a channel trends southwest and spreads out on a delta on a level with a well

defined beach on or near sections 6 and 7 of the town next south. From the same gap a terrace, 40 to 60 feet higher, leads more directly southward toward McIntosh. In this terrace is a row of large basins and lakes with abrupt sides.

(*b*). There is a notable chain of lakes extending southwest from Leech lake, which is utilized by the Indians for a trail. It crosses T. 141, 32, and 140, 33.

(*c*). Several shallow winding channel-like swamps are found traversing interruptedly the plain forming the divide between the Clearwater and the Mississippi.

Striæ.—These are found abundantly on the surface of the only rocks found in the region, capable of receiving and preserving them, viz.: at the Lake of the Woods. Their direction is generally southwest, or parallel with the axis of the southwestern bay of the lake. As the magnetic needle was useless, note was taken with reference to the sun, but the results have not yet been calculated.

3. *Lacustrine and Recent Formations.*—Large portions of the region visited were formerly the bed of lake Agassiz. The several beaches of the lake were frequently traversed. We may enumerate and locate them as follows, beginning with the highest; we use local names, as their correlations are not certain:

(*a*). The Lindsay beach. This seems to intersect the moraine on sec. 31, 150, 40, and runs nearly south for three or four miles at least. It was first seen from the west and photographed with the thought that it was a terrace of Hill river.

(*b*). The Baudry beach. This passes east of north near the station Baudry. It was not closely examined. This is believed to correspond to some indistinct fragmentary beach lines noted along west of the south courses of Thief and Red Lake rivers, and possibly with the next.

(*c*). The Excel beach. This is well developed and nearly continuous, extending along the east lines of T. 155, 44, and 156,44. This, I believe, is sometimes called Oak ridge.

(*d*). The Higher Gentilly beach. Along the east side of Town Gentilly, 150, 45, are two sand ridges, one about 15 feet higher than the other. They are about 200 yards apart and a canal-like pond runs between them for some distance. Approaching the river north they turn westward and are said to pass Ives Station or ridge. They were found still together along west of the east line of T. 156, 46, and were observed between the Tamarac and Middle rivers.

(*e*). The Jadis ridge. This probably is a continuation of the last. It was followed from the northwest corner of T. 158, 46, north and then east-northeast past Pelan and Badger to sec. 22, T. 162, 40, near Jadis. It is a most imposing feature, forming a perfect thoroughfare through swamps and timber. It is grassy along its top, with oaks and elms on its slopes. It is often 18 to 20 feet high, with a breadth of 300 yards when of simple structure. It is at several points double or triple, with cross ridges. At its eastern extremity it ends in an abrupt curve to the south. It is there about 65 feet high above the plain east, with lower terraces at 12 and 38 feet above the same. It will be noticed that this is about the hight of the bouldery ridge mentioned under moraines (*l*).

(*f*). The Lower Gentilly beach. As before said there are two ridges nearly parallel along the east side of T. 150, 45. It is found in company with the Higher, where we met with it, till both have crossed the Tamarac, then the lower is said to turn northwestward to the vicinity of Hallock. The Pembina trail follows it. We were not so fortunate as to determine the exact point where the two separated.

(*g*). The Foldal beach. Another well defined ridge was found about parallel with the last. It was crossed on sec. 4, 156, 46, and on or near sec. 24, 158, 47.

(*h*). Nelson's beach. Running east through the third tier of sections in T. 162, 39, is a low sandy beach, not more than 10 feet above the surrounding flat. I judge that the inner side is north, but am not certain. It seems to mark the north side of an old delta of the Roseau river.

Bouldery Strips.—The inner sides of the ridges are bounded generally with clayey flats quite thickly strewn with boulders, so much so as to interfere seriously with their tillage when dry enough to farm, and with mowing when used as hay-meadows. This feature is easily explained by the wash of waves and the undertow, while the adjacent beach was forming. In places they are so abundant as to suggest that floating ice may have assisted in collecting them. As Mr. Upham has already observed, boulders are rarely if ever found on the beach itself. I found one boulder of limestone about 6 inches in diameter on the summit of the lower beach in Gentilly, and one or two larger on Nelson's beach. The body of the beach is usually sand and gravel, the latter rarely coarse. Boulders however are found close to the beach and not far below the summit.

Clay Flats.—Extensive areas inside and remote from a beach are commonly covered with fine clay. This is the case about Stephen and I understand between there and the Red river, and so generally north and south along the bottom of the Red River valley.

About Red Lake Falls, as was finely shown in fresh railroad cuts, there is a deep deposit of dark laminated clays of fine grain. There is a layer of dark clay ⅛ to ¼ inch thick, then a loose light-colored deposit not more than a tenth as thick, which shows plant-like structure of some Algæ compressed. These deposits, though 20 feet in depth, in places are quite inconstant in thickness and sometimes pass abruptly laterally into sand. In the Roseau valley a similar formation was observed in freshly dug wells. A case was reported as follows, near Roseau lake: Eight feet below the surface this laminated clay was struck and was 8 feet thick; then sand, red clay and pebbles for 23 feet; then the laminated clay again, which continued down as far as 160 feet from the surface.

In Ross township near by a well was dug 110 feet deep all in this laminated clay, and from that depth the water rose to the surface. This was reported by Schoonover.

River Terraces.—A few only of the more notable may be mentioned here. Along the Clearwater, about Bagley dam, a sand terrace 25 to 30 feet above the stream is quite widely developed. A section below the dam showed the full hight built of obliquely stratified sand with a bouldery stratum about the middle.

At Red Lake Falls another section on the same stream was as follows:

20 feet. Dark lead-colored laminated clay, with very few pebbles. [Lacustrine.]

10 feet slope and undetermined, but from other sections, presumed to be occupied by the strata above and below.

8 feet. Yellow loam stratified, in places passing into fine sand. Bottom well defined.

7½ feet. Typical till, light bluish gray.

5½–3½ feet. Stratum of boulders above and laminated pebbly loam below.

19 feet. Lighter, looser buff till.

4–5 feet. Bouldery slope.

Level of Clearwater below the rapids.

The upper portion of this is doubtless lacustrine, and perhaps none is strictly stream terrace.

Topographical Notes.—In the basin of Red lake and of lake Agassiz the surface is very level and largely marshy. Elevations over five feet above the general level are rare, with the exception of the beaches and moraines already noted.

The divide between the Mississippi and the Wild Rice and Clearwater rivers is similarly even and marshy, but about 150 feet higher.

Mr. W. J. Hilligoss, of Fosston, an experienced surveyor and hunter, called my attention to the fact that the general level of the land south of the following line was about 100 feet higher than the general level of the plain north of it. The line he described as follows: Beginning on the west slope of the highland a little south of the Wild Rice, T. 144, 41, it goes in a sinuous line eastward to Schoolcraft river, and thence southeast towards Leech lake. Where I crossed it, I found his statement to hold good.

The existence of this buried escarpment, if such it be, may explain why the ice lobe from the east pushed over the divide between the Mississippi and the rivers northwest, as has been stated, so as to form its moraine on the slope northward.

Capt. Mockman, of Jadis, of wide and intelligent acquaintance with the region, informed me that Lake of the Woods is several feet higher than Roseau lake, that a "muskeg" or marsh nearly connects them, and that a low ridge, not over 200 yards wide, is all that hinders the water running.

He also stated that the region between the Roseau and Rat rivers was "mountainous," traversed with northwest-southeast ridges, that Pine ridge runs northwest, and that there are bouldery flats on the boundary west of the Roseau.

J. E. TODD,

Assistant Geologist.

Vermillion, S. D., Dec. 20, 1892.

V.

FIELD OBSERVATIONS OF N. H. WINCHELL IN 1892.

THE HALE, CINCINNATI AND BIWABIK MINES.

Field observations were begun March 5, 1892, by a hurried trip to the new mines then lately opened on the Mesabi range in secs. 1 and 2. T. 58-16. The report on the "Iron Ores of Minnesota" (Bulletin VI) had but lately been published, and had announced some of the early discoveries, but at that time none of the remarkable deposits had been found. It was not long, however, before some of the possibilities which that report had pointed out for the Mesabi range, began to take on the appearance of actualities. It was for the purpose of verifying some of these later discoveries that an early examination was made. At that time the Hale, the Cincinnati, the Shaw and the Biwabik mines were the center of interest and expectation, while further west the "Misabe Mountain" location, with numerous promising localities intervening, gave strong hope that the most glowing anticipations would be realized.

But little information was gained by this first visit to these mines, beyond the verification of ideas already published concerning the general geologic relations. At the Hale mine (S. W.¼ sec. 1, 58-16), the most easterly of the new group, the ore deposit was met with sometimes within two feet of the natural surface, and in some cases the turf itself grew in a red hematitic soil which resulted immediately from the disintegration of the ore. In other places the ore was found ten or twenty feet from the surface. This mine is just south from a low ridge of greenstone, about ten or fifteen rods distant, which, at a little

further west, is replaced by granite. The ore, and the changed rock lies unconformably on these older rocks.

The Cincinnati mine property embraces eight "forties" in the central part of section 2, 58-16. At this mine the rock which intervenes between the ore and the greenstone is a rather loose quartzyte, which somtimes is charged with ore by downward infiltration. This intervening quartzyte is not visible at the Hale mine, but at the Cincinnati mine three shafts have penetrated this sand. Overlying the ore horizon is a series of slates, so called "black slates", although this rock is sometimes not at all slaty, but rather a black rock, fine-grained, in beds from four to twelve inches thick. The seven shafts which were examined on the Cincinnati property were all said to be in ore from five to fifty feet, although it was evident that this ore was not all of first class grade. These were all on the N. E. ¼ of the N. W. ¼ of section 2.

The Biwabik mine adjoins the Cincinnati toward the west, and several shafts here have entered ore of fine quality. Some of these shafts, which have been sunk by the simplest methods, and without the aid of steam power, have entered soft ore to the depth of over fifty feet, the overlying drift accumulations being from ten to twenty feet thick. Under the ore here also a sandstone has been encountered. Toward the north occurs the greenstone ridge which extends continuously from the Hale mine.

To reach these iron locations it is necessary at present to travel over an execrable road a distance of twelve miles from the Duluth and Iron Range railroad at Mesaba station. Over this road during the past winter much freight has been hauled, indeed all the lumber, supplies and all the personal accoutrements of the men here employed, as well as of those at Mountain Iron, have been hauled, at great expense, by horses, from this railroad station. This has caused the sudden influx of small traders and the establishment at the station of many transient fortune-seekers, resulting in a village of about a hundred temporary shanties.

MANGANESE OXIDE AT MONTICELLO.

Under the guidance of Mr. J. N. Stacy a visit was made (April 21) to the left bank of the Mississippi river at one mile above the village of Monticello. Here was found a bluff, about 25 feet high, (the usual bluff of the immediate river channel outside of the flood plain,) consisting of some strata of the

Cambrian, much hid by drift sand which falls from the top. The strata are of light green shale and white sandstone, the latter containing Lingula in considerable numbers, and belong in the St. Croix. This is an isolated cut by the river, inasmuch as generally the river bluff consists of drift, the lowest seen at the water level being a red till, or of fine stratified red clay. In the overlying gravel is much manganese stain. This here overlies a fine red brick clay, such as that used at Monticello.

On the west bank of the river, on sec. 32, T. 122, R. 25, is a considerable stratum of black manganese oxide. It extends visibly along the river bluff 200 or 300 feet, immediately overlying a pebley blue clay, and has an average thickness less than twelve inches. Overlying it is drift gravel and sand. The underlying blue clay extends indefinitely westward, and underlies also an extensive marsh in secs. 31 and 32. There is a suggestive topographic relation between this bog and the lower level at the river which leads to the supposition that this bog, which is itself affected with manganese and iron oxides, has its underground discharge into the river at this point. This supposition is strengthened by the existence of wad in greater or less amount over much of the surface of the marsh, mixed with greater amounts of bog iron ore. The perpendicular section at the marsh was found to average about as follows:

Peat	1—2¼	feet.
Red bog iron	0—3	inches.
Black manganese and bog ore	0—2	feet.

Analysis made of the black deposit near the bottom gave but little manganese, the color being due principally, in this case, to organic matter. Analysis of the black deposit at the river bank, which first attracted attention, was given in the last report (p. 321), and is here repeated:

Sand and clay	4.98
Carb. lime	6.86
Carb. magnesia	.85
Oxide of iron	.51
Black oxide of manganese	79.83
Phosphorus	.09
Sulphur	.01
Water of hydration and organic matter	6.87
	100.00

THE MESABI RANGE ON SEC. 27, T. 60–13.

This is one mile south of the granite range. The land here is owned by the Mesabi Iron company and exploration is being made by the Mesabi Syndicate company, under the management of Capt. Wicks. Much expense has been incurred, the effort being to accomplish a thorough examination of a large tract of presumably iron-bearing lands. Capt. Wicks furnished much information, and guided the writer to several points of geological interest. He gave the following description of a drill-hole made in N. W. ¼ S. W. ¼ sec. 27, 60-13, one mile south of the granite. It is illustrated by samples of the rocks passed through, as numbered:

Diamond drill section, made on N. W. ¼ S. W. ¼ section 27, 60-13.

Drill No. 5.

1.	Drift	6 feet.
2.	Black and gray, fine, banded rock, with fine grained magnetite, the latter being distributed through the whole, and sometimes in beds six inches or ten inches in thickness. Survey number 1628	157 feet.
3.	"Black slates," a rather massive rock to be named slate, charged with magnetite. Survey No. 1629. Closely allied to the last	70 feet.
4.	Gray quartzyte, nearly all silica, but sometimes porous; has round secretions (or concretions), 1630A, shaped like the sponge Hindia, about ¼ to ½ inch in diameter. These are in cavities somewhat larger, but surrounded by a loose siliceous mesh which keeps them in place. This rock also has some non-homogenous places—angular and rounded masses appearing cut by the diamond drill. Survey No. 1630	20 feet.
5.	"Ore." This is a siliceous, fine magnetite. The upper part contains some of No. 4, and the lower part is softer, and rather less in iron. This lower part gave no core, but washed away with the cuttings through the drill core, suggesting that it may have been soft ore. Capt. Wicks thinks 18–20 feet may be the average thickness of the ore (1631)	24 feet.
6.	Fine grained, pinkish-cream colored quartzyte, evidently granular, though very fine. (1632)	17 feet.
7.	Round, "fragmental" quartz grains cemented in a matrix of quartz. The lower portion of this stratum is of crystalline quartz, or at least of less evidently fragmental grains Some of it also appears like chalcedonic silica. The crystalline portions present faces of fracture 1-16 to 1-4 inch across, and resemble the quartz seen at Chub lake. It also contains pyrites in streaks and crystals. The transition downward to the next is gradual. (1633)	15 feet.

8.	A hard, siliceous greenish rock, which contains many fragmental grains of quartz 1-16 to 1-8 inches across, some of them of a lavender blue color. While the mass of this is quartz it is colored apparently by fine debris from the earlier Keewatin greenstones of the vicinity, and should be considered the lower portion simply of No. 7. It also embraces rounded pieces from No. 10, and evident crystals of feldspar. (1634; compare 1637)........................	10 feet.
9.	The lower portion of No. 8 becomes coarse and irregular, lighter colored, with pyrite or chalcopyrite, resembling outwardly a coarse granite. (1635).......................	1 foot.
10.	Granite. (1636)..entered	3 feet.
	Total..	321 feet.

Additional notes on the foregoing drill section.

A number of other drills also have been made in the same region, and according to the records kept by Capt. Wicks the following data were obtained:

Drill No. 1. S. E. ¼ S. E. ¼ sec. 29, 60-13. Drift, 8 ft.; black slates, 38 ft. (No. 3 of drill No. 5, above); gray quartzyte, (taconyte horizon), 12 ft. (No. 4 of drill No. 5, above); mixed ore, (50 p. c.), 10 ft. (No. 5, of drill No. 5, above); pinkish quartzyte, the lower portion of this had some of the coarser, fragmental quartz, 19 ft.; granite, 4 ft; total, 91 ft.

Drill No. 2. S. E. ¼, N. E. ¼, sec. 28, 60-13. Drift 7 ft.; black slates, 52 ft.; gray and brown quartz, 15 ft.; dark gray quartz, 9 ft. (the last two being the taconyte horizon); ore, hard, mixed, 24 ft.; mixed ore, and brown, "soft stuff," 7 ft. 6 in.; soft, green rock, mixed with quartz, conglomeratic, 7 ft.; granite, 4 ft. 3 in.; total, 125 ft. 9 in.

Drill No. 3. Surface, 4 ft. 9 in.; black slates, 81 ft.; dark, gray quartz, 12 ft.; quartz, and a little ore, 4 ft.; quartz, with seams of ore, 4 ft.; quartz and magnetite, 9 ft. 6 in. (the last four being the taconyte horizon); soft material and hard ore, 9 ft.; brown (pinkish) quartzyte, 32 ft.; white quartz, coarser, 8 ft.; granite, 4 ft.; total, 168 ft.

Drill No. 4. S. E. ¼, S. E. ¼, sec. 29, 60-13. Drift and boulders, 9 ft.; black slates, 36 ft.; mixed brown and gray quartzyte, (on the horizon of No. 4, of drill No. 5, above), no ore, 17 ft.; brown quartzyte and ore (six feet of ore in the core interbedded with the quartzyte, ore beds, 4 or 5 inches), 9 ft. 6 in.; hard ore, 14 ft. 9 in.; brown rock, soft, containing ore (30-40 p. c.), 2 ft. 9 in.; white fragmental quartzyte (bottom coarser), 10 ft.; granite, 2 ft.; total, 99 ft.

The rock of No. 6, of drill No. 5 (the pinkish, fine quartzyte), Mr. Wicks regards as complementary of the ore. Where it occurs he finds less ore, and that is impure, being mixed with this rock, and where none of this quartzyte is found, the ore, if found, is of high grade and clean. None of this rock is found in those holes where he has found the better ore. Mr. Wicks says he knows of this pinkish quartzyte in sec. 14, T.59-14, in angular pieces, evidently nearly in place; also in sec. 32, 60-13, where it is in outcrop.

The greenish, siliceous rock, No. 8 of drill No. 5, above, (Sur. No. 1634), is supposed to be in outcrop in N. E. ¼, S. W. ¼ sec. 22, 60-13, where a sample (1637) was procured from a pit 20 feet deep. This is a greenish, fragmental rock formed by debris from the adjoining granite and greenstone ridge holding conspicuous fragments of lavender-blue quartz supposed to be from the granite, and some orthoclase crystals, the latter eaten into by some agent, and showing within some of the green element which composes the matrix, and which apparently constitutes the most of the rock. Whether there be in this rock any volcanic diffusive debris, of a basic nature, is uncertain, but it appears possible, if not probable. Sometimes it contains pyrite and galenite. The general aspect is green. The rock is so soft that it cuts like semi-fibrous chlorite. In other places this member of the iron-bearing Taconic is rather a quartzyte, with green chloritic matter disseminated, the quartz grains being coarse and fragmental.

The rock 1631, the "ore" of the foregoing drill section No. 5, is seen fairly at No. 2 pit, which is on S. E. ¼ N. W. ¼, section 28, 60–13, where it embraces not only much hard, siliceous ore, but much coarser and some even conglomeratic masses and layers. The conglomerate is sometimes distinctly a conglomerate, and sometimes it appears like a cemented breccia, the matrix being "chalcedonic," or chemically deposited silica, very fine and flint-like, or hematite and silica. Sometimes the pebbles, or pieces of the breccia, are largely of flinty pieces of such silica also. In some of this are found the round sponge-like concretions (1630A), but they are rather in the more distinctly fragmental and finer layers, above the ore itself.

The rock of No. 8 of the section No. 5 (1634, also represented by No. 1637), is again repeated in No. 1638, in an extreme phase. It here shows so much coarse and rounded quartz that it should be called a sandstone, or a quartzyte. The green element supposed to have resulted, possibly, from volcanic

debris of the time, being so scant as to merely speck the broken surface, or to appear more abundantly in blotches. In other specimens the sand grains are nearly wanting and the resulting rock is green, soft, homogeneous, rather fine-grained, and referable to a volcanic tuff, being another extreme condition of the rock 1634.

No. 6 of the above drill section (rock 1632) is also represented by rock 1640, which was obtained from an outcrop in N. W. ¼ N. E. ¼, sec. 32, 60-13. It is a pinkish fine quartzyte, and an interesting rock, both on account of its character and its associations. It weathers usually reddish or brownish. It appears pinkish in the drill cores, and on deep fresh fracture it is bluish and grayish. It is marked by the plainest sedimentary bands, which become evident when the rock is seen on a large scale. It is essentially a quartzyte, and it lies below the iron horizon, *i. e.*, the so-called iron horizon here, and is overlain also by a small amount of non-fragmental siliceous rock, a chalcedonic rock which grades off into the dark gray and irony layer above. This fine and chalcedonic belt is about 3 feet thick, but it is not all chalcedonic. It is sometimes made up of coarser and "fragmental" quartz grains. No. 1640, however, is in a sense intermediate between the chalcedonic and the fragmental. It may have been derived by chemical precipitation in the Taconic ocean, for it is very fine-grained; but it has none of that curly agate-like banding which characterizes the "chalcedonic" agate-like silica. This rock runs through two or three sections at least, and affords some outcrops in a series of bluffs south of the outcropping granite range. We could not see any place where it lies on anything, but it seems to come close to the granite. In the drill it was found to overlie some of the coarser fragmental quartzyte, but no great thickness of it. The most interesting point about this is its similarity of lithology and its probable identity of stratigraphy with the Wauswaugoning and Pigeon Point quartzyte, indicating the equivalence of the Peewabic quartzyte with the Wauswaugoning.

There are here three conditions of quartz, each one making rock masses:

1. Agate-like and banded, so-called chalcedonic quartz, very fine-grained, non-fragmental.
2. Very fine-grained, bedded, pinkish or brownish quartz, partly fragmental, but largely a chemical oceanic precipitate.
3. White, coarse-grained, fragmental quartzyte, mingled not only with quartz chemically precipitated but with green (tufaceous?) materials.

A dike of igneous rock.

A large green dike runs S. W. and N. E. in N. W. ¼ N. E. ¼ section 32, 60–13, and seems to have some connection with an irregularity detected by Mr. Wicks in the iron formation, indicating a fault. But it seems to play no such roule as has been described respecting the dikes cutting the iron-formation on the Gogebic range. It appears to stand about vertical but its width and extent longitudinally could not be made out. It could be traced about 10 rods. This is the first dike the writer has seen on the Mesabi range cutting the iron-bearing rocks.

May 10. Returning past Mallman's camp (mentioned in Bulletin No. VI, pp. 135 and 202), an examination was made of the new working. Nothing new was developed. No more merchantable ore has been discovered. The work ceased, but is being renewed by other parties.

It seems from all that I can learn of the ore-bearing qualities of the eastern part of the Mesabi range, and from the results attained by the explorations that have been made by those owning the lands, or by their lessees, who certainly should be considered to be the best qualified to develop the ore deposits which the country might possess, that the outlook is not so favorable for ore in the eastern part of the range, at least in that portion eastward from Mesaba Station to Birch lake, as in the western. The ore is more likely to be magnetic, and, while magnetism itself cannot be said to be injurious, the ore is so closely mixed with siliceous impurities, or is so sparsely interleaved with the rocks of the formation; that it is not found to be profitable to work it. It is very likely that the presence of the eruptive rock in greater nearness to the ore-bearing localities has been a powerful cause in rendering the ore magnetic. The same agent has affected the associated rocks, particularly the quartzyte underlying the ore.

REPUBLIC, MICHIGAN.

In about an hour and a half a brief examination was made of the Republic mine. It is evident at once that the great hill of jasperoid hematite first encountered in going south from the depot of the Duluth, South Shore and Atlantic railroad, is in the Keewatin. It duplicates perfectly the hills and ridges at Tower. Granite and associated rocks extend almost all the way from Humbolt, where some hornblendic rocks appear. The ore is micaceous, standing vertical, and is interbeded with

a coarse quartzyte. This last fact occurs immediately southwest from the old working shaft which is on the top of the hill nearest Humbolt. This coarse quartzyte is also stained greenish by some mineral (olivine ?) disseminated through it which is hard, resembling quartz, but apparently distinct from the quartz. In this quartzyte is also hematite in glittering micaceous scales and patches, and a sparser amount of light-green softer sediment, resembling the green sediment derived from erosion of the Keewatin. This quartzyte extends visibly a couple of rods and has a width of 5 or 6 feet. It acquires a gray color, as the hematitic ingredients and the jaspilyte gradually fade out, constituting a rock which is then indistinguishable from some of the siliceous graywackes of the Keewatin.

Further down along the face of the cliff, near the base, on the southwest side, this greissen is more visible, but it appears here also as an integral part of the Keewatin formation, and is seen to blend with it toward the southwest both slowly and abruptly, but near the ore toward the northeast it becomes coarse and conglomeritic with large fragments of the ore.*

On the east side of the main ridge is a large area of greenstone, but the rock is much darker and harder, and more evidently eruptive, than most of the Keewatin greenstone. In some places it approaches a hornblende schist, and in others it cuts, as if eruptive, through the sedimentary rock of the ridge.

ISHPEMING, MICHIGAN, WINTHROP MINE.

May 12, 1892. At the Winthrop mine, which is in the hill range south of town in which is also the Saginaw mine, the rock and ore dip north about 45 degrees. The ore is hematite with some limonite, and is semi-soft and porous. Some of it is siliceous, and appears like the taconyte of the Mesabi range in Minnesota. I judge the mine is in the Taconic. Greenstone knobs appear to the north and northeast, but not in the immediate vicinity of the mine. A little further west, however, appears a range of greenstone hills which would strike a few rods south of the mine.

The Saginaw mine.

In the sixteenth report of the Minnesota Survey the writer announced for the first sime a general non-conformable contact

* This is more lately referred by Van Hise and other members of the U. S. Geol. Survey to an overlying basal conglomerate of the "Upper Huronian," a parallel of the non-conformity seen at the Saginaw mine.

between two iron-bearing members of the "Huronian" in the Michigan iron region, and illustrated the non-conformity by two diagrams sketched on the spot, one at Cascade, south from Negaunee, and one at the Saginaw mine south from Ishpeming.* This examination was made because in Minnesota such a non-conformity had been discovered between two iron-bearing formations, which had been traced a distance of over a hundred miles. It was thought that a similarly profound non-conformity probably existed in Michigan and Wisconsin. Without it there could be but little progress made in any attempt at co-relation between the rocks on the opposite sides of the lake Superior basin. The discovery of evidences of this great break in the iron-bearing series at the typical localities in the well-known mining region of Marquette brought about a general concordance between the Archæan and Taconic geology of Minnesota and that of Michigan and Wisconsin, and at once confirmed the grand conclusions which had been reached from a field study of the same rocks in Minnesota.

Subsequently Prof. Van Hise, in reviewing the "Apparently conflicting views of lake Superior stratigraphy,"** attempted to show that not only had this non-conformity been seen and recognized by several other geologists, but that the explanation given by the writer was incorrect. As this is an important point as to the correctness and priority of this interpretation it will be well to review briefly the evidence adduced by Prof. Van Hise.

He refers to Foster, and Foster and Whitney***, and to T. B. Brooks†, C. Rominger‡, M. E. Wadsworth§ and R. D. Irving§§.

An examination of this literature shows the following facts: Mr. J. W. Foster made a reconnoissance under the direction of Dr. C. T. Jackson in Sept., 1848, of "the country lying between lake Superior and Green bay." His report is dated Boston.

*Sixteenth Annual Report Minnesota Geological Survey, pp 43-49, for the year 1887. Submitted for publication March 20, 1888.

** American Journal of Science, [3], XLI, 117.

***Report on the mineral lands of lake Superior. J. W. Foster. Ex. Docs., 1848-49, 2nd Series, 30th Congress, vol. ii, no. 2, p. 161. Geology of the lake Superior land district. J. W. Foster and J. D. Whitney. Senate Docs ,1851, Spec. Sess. 32nd Cong., vol. iii, no. 4, pp 23, [22], 43, and 67.

† Iron-bearing rocks of the Upper Peninsula of Michigan. Michigan Geological Survey, 1873, vol. ii, pp. 128-129, 133.

‡ Upper Peninsula of Michigan. Mich. Geol. Survey, 1881, vol. iv, pp. 74-75.

§ Notes on the geology of the iron and copper districts of lake Superior. Bull. Mus Comp. Zool., 1880. vol. vii, pp. 30-31.

§§ Preliminary paper on an investigation of the Archean formations of the Northwestern states. Fifth Ann. Rept. U S. Geol. Survey, 1885, p. 193.

May 26, 1849. On p. 759* he states: "We explored this ridge on section 1, township 46, range 30, and found that it is composed for the most part of nearly pure specular oxide of iron (fer oligisté). It shoots up in a perpendicular cliff one hundred and thirteen feet in hight, so pure that it is difficult to determine its mineral associations.

We passed along the base of this cliff more than a quarter of a mile, seeking for some gap through which we might pass and gain the summit. At length after much toil, and by clambering from one point to another, we succeeded. Passing along the brow of the cliff, forty feet, the mass was comparatively pure; then succeeded a bed of quartz composed of rounded grains, with small specks of iron disseminated, and large rounded masses of the same material enclosed constituting a conglomerate. This bed was fifteen feet in thickness, and was succeeded again by specular iron, exposed in places to the width of one hundred feet, but soil and trees prevented our determining its width."

The place here described is about one mile northwest of Republic mountain, and undoubtedly in the same general belt. There is here no evidence that Mr. Foster realized the significance of this conglomerate. He only says, regarding it, "constituting a conglomerate," without drawing any inference. Indeed, considering the grand conclusion which Messrs. Foster and Whitney reached concerning the divisibility of the Azoic, it would hardly be a fair interpretation to suppose that he here knew he was at the horizon of the most profound and widespread non-conformity known in the region.

The first reference to Foster and Whitney's report on the lake Superior land district, (p. 23, it is actually on p. 22,) is in almost the same terms as that quoted above, and is evidently the result of the same visit. Its most important variation from the original of Mr. Foster is the insertion after the word "conglomerate," of the words *or breccia*, thus allowing the possible hypothesis which is more fully brought out on page 43.

* This quotation is from that *omnium gatherum* of geological, mineralogical, topographical, barometrical and botanical reports usually known as *Jackson's report*, although in the same collection is found also the preliminary report of Foster and Whitney, dated Nov. 5. 1849, giving lists of lands which they recommended to be reserved for minerals, and "Reports on the linear surveys, with reference to mines and minerals in the northern peninsula of Michigan in the years 1845 and 1846," by William A. Burt, Bela Hubbard, S. W. Higgins and others, under Dr. Houghton's contract. It was the result evidently of giving to the public printer all the reports accumulated since 1844 on the region of northern Michigan, without editing, and the publication of the same without any attempt to give them any logical or chronological order.

The second reference to Foster and Whitney (p. 43), is in the following terms: "On the line between sections 29 and 32 [T. 46, ranges 26 and 27], is a remarkable knob of conglomerate, alike interesting from the fact that such a form of rock is of rare occurrence among the Azoic series of this district, and from its intimate connection with the origin of the masses of iron in its vicinity. The conglomerate forms here an isolated, rounded elevation rising at least 100 feet above the general level. It is made up of coarse blocks of various sorts which belong to the neighboring trappean and slaty beds, and are of very considerable dimensions. Among them we recognized not only fragments of the rock associated with the iron, but masses of the iron itself, and of the banded and jaspery varieties. Most of the fragments of this remarkable breccia are but slightly rounded and worn on their edges, having in this respect much more the appearance of a friction-conglomerate than of one in which the long continued actioh of water had played a part. The blocks are cemented together by a very hard ferruginous paste. The nature of the surrounding country, covered with soil and forest trees, prevented us from satisfactorily tracing its connection with the adjoining rocks. We are inclined, however, to regard it as connected with the eruption of the adjacent granite, and rather as the effect of the crushing and elevating forces which such an elevation must have called into play. If this is the case it may be considered as analogous, in its mode of formation, to the conglomerates of Keweenaw point. A fact worthy of notice in this connection is, that, in spite of the heterogeneous structure of the mass, it exhibits a distinct tendency to separate or flake off in thick concentric layers like some eruptive granites.

The nature of the fragments composing this breccia, and of the cement by which they are united, proves conclusively that the process of formation of the ores of iron, and the impregnation of the slaty rocks with metallic matter, must have been one of long continuance and not a merely momentary operation. The various kinds of ore must have been in existence before the formation of this mass, but they were subsequently broken off and mingled together in confusion. Emanations of metallic matter must still have been issuing from beneath, since we find the whole deposit thoroughly impregnated with it, and converted into one firmly coherent mass."

The significance of this extract needs no elucidation. It is only necessary to call attention to its bearing on the interpre-

tation which Prof. Van Hise seems inclined to give it. It is plain that such an interpretation would have been repudiated at once by the gentlemen responsible for the words quoted. It was presumed by them that they saw a breccia due to upheaval and crushing instead of a conglomerate marking a wide-spread non-conformity in the "Azoic."

The third reference to Foster and Whitney (p. 67), shows the following:

"The Azoic period having been one of long-continued and violent mechanical action there is no reason to doubt that many of the strata of which it is composed may have been derived from the ruins of previously formed rocks of the same age, both sedimentary and igneous. This is clearly shown to be the case in the remarkable knob of conglomerate described on page 43 [quoted above], which contains rounded fragments of the various kinds of ore found in the adjacent region."

This description refers to the same occurrence as that last noted, and simply repeats the supposed effect of local disturbances and destruction of some of the earlier formed rocks of the same age. It would be very far from the truth to suppose that Messrs. Foster and Whitney here suggested a possible plane of separation between two parts of the Azoic, for it was one of their final conclusions that the Azoic could not be subdivided on any chronological or petrographical basis into recognizable and widespread members.

The first reference to T. B. Brooks (in vol. i, instead of vol. ii) shows the following:

"The upper quartzyte at Republic mountain is a gray massive rock, sometimes banded, and, near the contact with the iron, sometimes conglomeritic, containing large and small flattened fragments of flaggy ore."

The second statement of Brooks referred to is:

"Overlying the ore formation here [Saginaw and New England mines], is the upper quartzyte, XIV, dipping at a low angle to the north, as may be seen just north of the Parsons mine. This quartzyte again comes to the surface about half a mile north, in a flat synclinal where it again dips north and does not rise until we reach the new Excelsior mine, owned by the Iron Cliff Co., which is shown on the section.

"Returning to the New England mine we find between the ore XII, and the quartzyte XIV, a mass of specular conglomerate, somewhat similar to that described as existing at the Republic mountain, where it was regarded as belonging to the

ore formation. The fact that it overlies the pure ore at this locality, and has lithological affinities with some of the conglomeritic varieties of the upper quartzyte, leads me to doubt in which formation it should be included. I incline to the view that belongs to XIV."

There is no indication in this that Mr. Brooks thought he here was at a separation plane of great importance. Indeed his doubt as to whether the conglomerate belonged with the ore or with the quartzyte shows that it was not a question, in his mind, of moment. The word "formation" here was simply the general word used to designate one of the twenty parts into which the Huronian was divided by him.

The reference to Dr. Rominger's report shows that he likewise encountered this "brecciated" condition of the basal portion of the quartzyte, and also that he comes nearest of any writer, up to that date, in comprehending its import.

"A very rich seam of ore is almost invariably found on top of this jasper-banded rock-series, immediately beneath the quartzytes which form the terminal strata in all these exposures. This upper ore belt is almost regularly brecciated in its upper part, and the same is true of the lower quartzyte beds; which often are a mixture of ore-fragments with quartzyte pieces held together by an arenaceous cement. *As this is the case in nearly all the mines of the district, we must suggest that disturbances of not only* [i. e. not merely] *a local extent must have occurred at the end of this era of iron sediments.*"

It is evident, however, not alone from the above statement, but from many references to the probable cause of these irregularities which are scattered through Dr. Rominger's report, that he entertained a view similar to that of Messrs. Foster and Whitney. Eruptive action of igneous rocks, in his opinion, was solely responsible for these breccias and plications. So far was he from making a profound stratigraphic separation of the rocks of the Marquette district at the base of this conglomerate, as one might suppose from the fact that he is quoted by Prof. Van Hise, he entirely ignored it, and extended his iron group upward so as to include it, thus separating it wholly from the quartzyte with which it belongs and of which it presents simply the initial phase. It was after the writer had discovered such phenomena as proved the duplicate nature of the iron-ore formation in Minnesota that he studied carefully the report of Dr. Rominger, and he referred to his (Rominger's) report to call attention to facts in the Marquette district which, when

properly interpreted, bore out his general interpretation of the rocks of the lake Superior basin, and showed that *there also* there were two non-conformable iron-bearing formations, and that there *were two iron horizons instead of one*, and that they could be stratigraphically distinguished if time should be given, by a competent geologist, to work it out*.

Prof. Van Hise's quotation from Dr. Wadsworth is as follows:

"These [*i. e.* quartzytes and coarse fragmentals] of course mark old beaches water-worn after the jasper and ore were *in situ* in nearly their present condition, and, if the logic of the geologists of the Michigan and Wisconsin surveys were carried out, these unconformable detrital formations would mark a new geological age."

When it is remembered that the chief result of Dr. Wadsworth's effort was to prove the jaspilyte had an eruptive origin, and thus to controvert the "logic" of the Michigan and Wisconsin geologists, and that he attributes such appearances to the intrusion of the ore and jasper (jaspilyte) through the surrounding rocks, and the later protrusion of the granite (*i. e.* the greisen or modified quartzyte as at Republic Mountain) through the jaspilyte and earlier rocks, no one should have the hardihood to quote him as authority for the structural break that is here considered. That he saw, as others did, the rocks exhibiting these structures, is of no import so long as he did not assign the structures to their proper cause. Again, the writer has never, as yet, encountered a statement of the "logic" to which Dr. Wadsworth refers, applied to this horizon in the iron regions of Michigan and Wisconsin, prior to the date of Wadsworth's paper. Logic of that kind applied to this important horizon would have constituted one of the brightest spots in the able reports of the geologists of Wisconsin and Michigan, and would ere this have attracted much attention.

As to Prof. Irving, Prof. Van Hise makes the following remarkable statement:

"The real significance of the break was recognized by Prof. Irving, who not only found it in the Marquette district but knew of its equivalent in the Vermilion lake district of Minnesota."

For authority for this statement he quotes the following from Prof. Irving's paper on a "Preliminary investigation of

*Geol. and Nat. Hist. Survey of Minn 17th annual report, for the year 1888, pp. 43-44

the Archean formations of the Northwestern States," in the Fifth Annual Report of the United States Geological Survey, published in 1885, p. 193.

"I refer to the occurrence in the quartzytes overlying the ores, at several of the Marquette mines, of abundant rounded fragments derived from the ore below. A very much more striking occurrence of this kind is met with in the Vermilion lake district of Minnesota where the fragments included in the conglomerate overlying the iron belt are often several feet in length and angular. That these fragments prove the existence of the jaspery and chalcedonic material in its present condition before the formation of the quartzyte is sufficiently evident."

Far be it from the writer to attempt to detract from the brilliant halo that surrounds justly the name of Irving. Far be it also from the writer to put words and sentiments upon his pen which do not belong there. Justice is keen-eyed, and will allow no more favors to a deceased geologist than she would to him when living. That is all that Prof. Irving would ask of his successors, and that is no less than his successors are bound to yield to his work. It is found sometimes that it is an injustice to attribute opinions to a geologist which he does not entertain, and which he may never have expressed. It appears to the writer that Prof. Van Hise is liable to a charge of such injustice toward Irving, not to mention others.

There is a speciousness in the manner of presenting Prof. Irving's statement which can only be made apparent by a slight consideration of the subject. It will be found, on consulting the fifth report of the U. S. Geological Survey, page 193, and some of his later papers, that three very important facts are suppressed by Prof. Van Hise, which bear directly on the understanding that should be entertained of Prof. Irving's statement, viz.:

1. Irving does not give the facts on his own authority, but on the authority of Dr. Wadsworth. He says:

"Wadsworth has drawn attention to a very interesting occurrence at numbers of points in the Marquette region, and has made use of it to sustain his theory of the eruptive origin of the jaspery ores. I refer to the occurrence in the quartzyte" etc., as quoted above.

2. Irving is not discussing the stratigraphy in this connection, nor any question connected with the stratigraphy of the rocks of the region, but the origin of the cherts and the ores. His desire is to bring out the fact, which is a very important

one, that *the ore was completed in its construction and composition during the time of the formation* in which it is found, and that, inferentially, there has been no progressive accumulation or concentration of the ores, at least on a grand scale, in subsequent time.

3. Prof. Irving did not look upon this as a break, or non-conformity in the stratification, either at this time or subsequently. This is evident from the fact that he puts into his upper, or "iron bearing member" all the strata here concerned, viz., the quartzyte, the conglomerate, the iron ore and the green schist. His plane of separation was largely a theoretical one, derived from a consideration of the difference in crystalline condition manifested by the two ends of the series. The upper one he found to be evidently clastic, and but little crystalline, the lower he found wholly crystalline. The separation was by him put between these distinctions, and he placed it theoretically above the crystalline schists and the Laurentian. In no place does he refer to this plane of non-conformity with the proper understanding of it. He refers to the contact of the "quartztye" upon the Laurentian, but he then, in all cases supposes he is considering a quartzyte underlying all the ore, and (if he mentions it) also the green schists. His plane of non-conformity would apparently be that which Dr. Wadsworth has more lately reported to occur between his Cascade and Republic formations, where he describes a conglomerate like that which exists at the plane under consideration.* This lower break also has been noted by Van Hise in the same paper here criticised p. 117). It is a curious fact, however, that while Irving theoretically referred to this lower break, all his cited examples belong to the upper, and that he failed to give significance to it at the horizon to which his examples pertain. Of this error Dr. Wadsworth has said:

"While Irving was correct [though at a later date than the writing of this paper quoted by Prof. Van Hise—N. H. W.] in the observation of the conglomerates, he was wrong in his views of their position in the geological column, and thus actually overturned the series. This mistake of Irving's exercised a powerful influence upon his work and upon his views concerning the origin of the iron ores and the jaspilyte.

"It is very unfortunate and confusing in the history of geological opinion concerning these basement conglomerates, that

*Report of the Michigan State Board of Geological Survey for the years 1891 and 1892, (1893), pp. 114, 116.

Van Hise has overlooked this mistake of Irving's, and speaks as if Irving had the same views as himself, i. e. that the conglomerates overlie the lower series of iron-bearing rocks, when Irving clearly and distinctly held that these conglomerates were at the base of all the iron-bearing rocks." Op. cit., p. 114.

It is plain, therefore, that Prof. Irving did not "recognize the significance of this break," as claimed by Prof. Van Hise. It is also plain that no one understood it prior to the interpretation put on it by the writer in the 16th annual report of the Minnesota survey, pp. 43-47, 1887. Instead of admitting this priority, Prof. Van Hise diverts the reader by inconsequential criticisms of some of the details of the illustration accompanying the description.

It is not necessary here to enter into the question of the existence, or not, of such a break in the Vermilion lake district. It is only necessary to repeat that in Prof. Irving's reference to that region, in this connection, he does not intimate that there is any such break. He only refers to evidence which he had seen there that shows the iron ore was fully formed prior to a fracturing which it suffered. The large pieces "several feet in diameter" evidently were parts of a remarkable breccia which has since been examined in the region north of Soudan. No data were given by Irving to show where his observation was made, but as the members of the Minnesota survey have not been able to find any conglomerate holding such pieces, but only coarse breccias (reibungs breccias) which could not at all answer to the brief description given by Irving, it is sufficient to say that probably the feature seen by him at Tower, should not be considered as pertaining to the horizon of the conglomerate now known at Marquette.

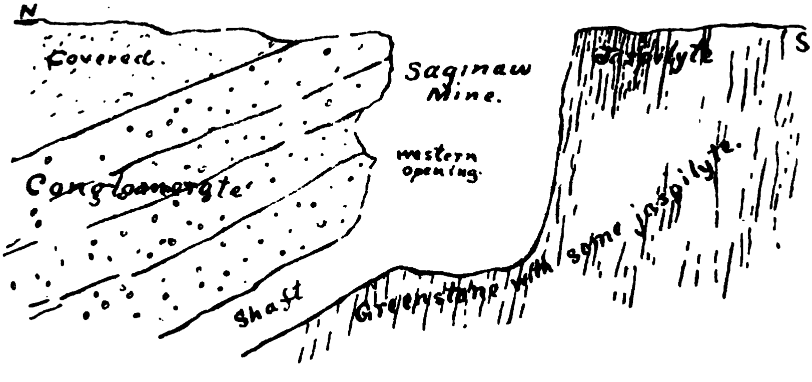


FIG. 1.—Section N. and S., at the western opening of the Saginaw mine.

The re-examination of the Saginaw mine resulted (in May, 1892) in no material correction of the views presented in the 16th Minnesota report already referred to. At the western opening, which is nearest the Goodrich mine, the stratigraphic relations were sketched carefully, as shown in the figure opposite (Fig. 1).

At this pit the later iron-bearing strata lie non-conformably upon the older. The jaspilyte is seen to fade out into the green schist. The overlying conglomerate is coarse with water-worn quartz and jaspilyte pebbles, and with much iron. It is simply the basal conglomerate of the Taconic affected by proximity to the jaspilyte beds of the Keewatin. The sloping shafts are run mainly in the greenstone, below the conglomerate, but the ore worked is associated with the Taconic conglomerate. The exact contact of the conglomerate on the greenstone is indistinct, as it is often on granite, but the dip, structure and lithology change within the space of six or twelve inches. The fragmental iron here worked was in the Taconic, very different from that at Republic, though the ore from the two is essentially the same. The eastern

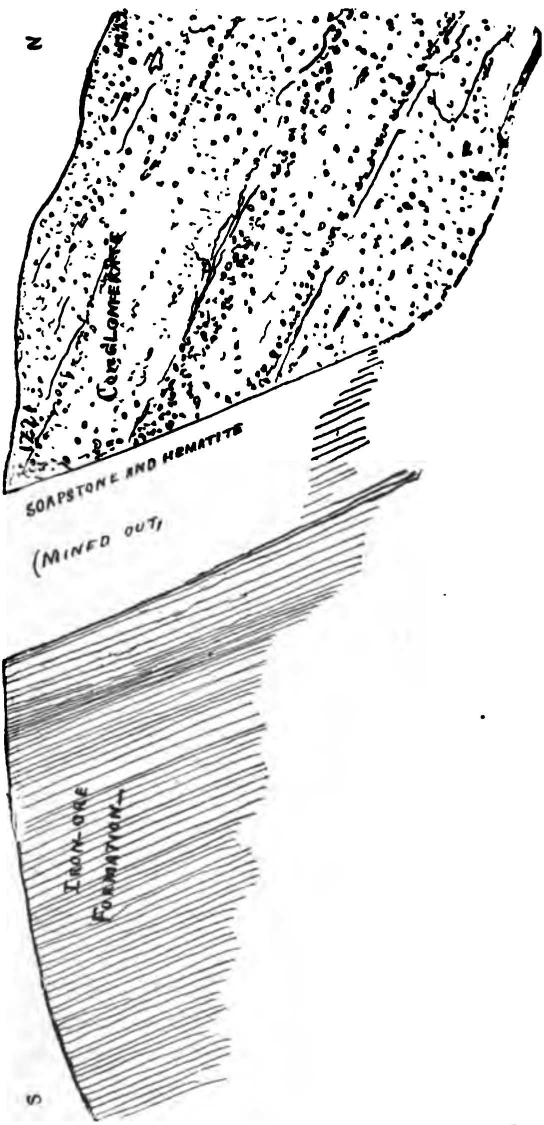


FIG. 2.—Section N. and S., at the eastern opening of the Saginaw mine.

opening of the Saginaw mine is that examined and figured by the writer in the Sixteenth Minnesota report. Here the conglomerate lies also non-conformable on the Keewatin, and the latter consists partly of greenstone and partly of a poor hematite—an ore that is siliceous and grayish, rarely banded like the jaspilyte of the formation—yet distinctly Keewatin, although hardly an ore of any merchantable quality. At this particular point there is an inclination northward in the Keewatin jaspilyte, and that is the ore formation represented in the figure in the sixteenth report as unconformably under the conglomerate. The two approximate the same dip, though they do not have the same. The figure is here repeated. It needs no correction (Fig. 2).

It is apparent that the criticism of Prof. Van Hise is wholly gratuitous and misapplied. These figures are produced from sketches at the Saginaw mine, while he assigns them (at least the latter) to the Goodrich mine, of which he gives a diagram*.

At the Goodrich mine the following diagram was drawn, which is quite different from that shown by Prof. Van Hise, from the same mine. This was made at a point some distance east of the large open pit, and on higher ground. It is evident that the direction of structure in the jaspilyte bands is continually changing, and that it is a character of no importance, whether they are nearly parallel or nearly perpendicular to the bedding of the conglomerate. The jaspilyte here is nearly perpendicular, twisted, but in the main running about east and

FIG. 3.—Section at the Goodrich mine.

west. On the very summit of this ridge is a bared spot which fortunately shows the exact contact of the conglomerate, mostly made up of fragments from the jaspilyte, upon the jaspilyte itself. This line of contact is traceable, on the top of

*American Jour. Sci. (3), XLI, 120.

the knob, for a distance of 25 feet. This is along the south side of the main pit, but north of another pit and deep working which has really been done in the Keewatin. Here, then, we have both formations iron-bearing and both considerably wrought. The shaft and working in the base of the Taconic slopes north about coincident with the dip of the conglomerate, and is quite regular, compared with the crooked shaft and underground working in the Keewatin which resembles the early Breitung mine at Tower. The ore from the conglomerate is hard and specular, and, as ore, is good, but it embraces pebbles of quartz and jasper, and is too poor for that reason. Still there is no doubt that much good ore was taken out here both from the Keewatin and from the Taconic.

This conglomerate becomes a well characterized white or reddish fragmental quartzyte at points remote from the outcrops of the Keewatin hematite. These observations are very important, and show, as I have before contended, that there are two non-conformable iron formations even in the original Marquette region. The Taconic ore here is wholly of fragmental secondary origin, *i. e.*, it is derived bodily, in form of detritus, from the underlying Keewatin, and there is no possibility of applying to it any substitution hypothesis to account for its origin here. The soft ore horizon of the Gogebic and Mesabi ranges is entirely above this conglomerate.

THE POTSDAM SANDSTONE AT POTSDAM, N. Y.

An excursion was made, in company with Dr. U. S. Grant and Mr. Charles Schuchert, into the region of the northern slopes of the Adirondacks. It is a singular fact that this region, in which centers the discussion of one of the perplexing problems of Paleozoic geology in the United States, has been substantially unexamined since the early work of Emmons and Mather, and that the uncertainty as to the age of the true Potsdam sandstone has rather increased as time has passed. This has resulted from the error which was made by all the early geologists who dealt with the "Potsdam sandstone," in applying that term to sandstones which, stratigraphically, are widely separated from each other, and to the [illegible] of determining to which of these horizons the true [illegible] belongs. It was hoped that an examination at a few

points would tend to solve the uncertainty*. The following notes were made.

Approaching the region from the northwest it was noticed that the country between Pembroke and Carlton Junction (Canada), as well as much of that south to Brockville, has been long submerged. The surface consists of a fine laminated, gray clay, sometimes seen 15 feet thick, without boulders or stones, and makes fine farms.

Sandstone. At Brockville is a hard, nearly white quartzyte. The same rock appears in islands in the St. Lawrence river, and along the shore at Morristown, where it is used, at the docks, for crib-filling. At the last place it is partially red, or reddish, bedded, weathering, at the river bank, into layers from two to four inches thick. From four to six feet in a perpendicular section are exposed at the dock. Between Morristown and Philadelphia this rock is seen much of the way. It is considerably quarried at several places, rising into hills and ridges from 20 to 50 feet high. Erosion gorges are cut in it to some extent, and these hills and ridges are the remnants left by such erosion. It appears to underlie some of the flat areas, but a few inches or feet below the surface, in a nearly horizontal position, and in other places it is tilted in one direction or the other, forming undulations. When broken, as in frequent anticlines, the strike is boldly presented. In the railroad grade cuts this rock is angular, sharp, rigid, much jointed. Along with these quartzyte exposures are also ridges of granite, especially toward Morristown. Indeed the road seems to cut through a granite area for many miles soon after leaving that town. The granite is reddish, both coarse and fine, and from the train could not, in some cases, be distinguished from

* Since this visit, which was made in May, 1891, two geologists of New York have made examinations in some of the northern portions of tho Adirondacks, and their preliminary reports are published in the Transactions of the New York Academy of Sciences, Vol. XII, 1893, "A Geological Reconnoissance in the vicinity of Gouverneur, N. Y." C. H. Smith, Jr.; "A review of work hitherto done on the Geology of the Adirondacks." J. F. Kemp. The latter gives a summary of the scant literature pertaining to this region prior to 1892, thus concluding: "In summing up the geology of the Adirondacks it may be stated that the following views relative to the stratigraphy of the crystalline rocks have been held:

I. It has been usually believed that the gneisses are the oldest and are metamorphosed sediments; that the norytes are later, some regarding them as igneous and others as metamorphosed sediments; that the limestones are latest of all.

If this be admitted and the norytes be regarded as igneous intrusions, how is it that no dykes or apophyses have been mentioned as radiating or offsetting from this enormous mass?

II. That there is a core of central and oldest noryte, having later gneiss as a metamorphosed sediment on its flanks, and still later limestones on both noryte and gneiss."

the red quartzyte. A conspicuous hill range, rising two hundred feet, more or less, extends for many miles parallel with the railroad, southwardly, beginning a few miles from Morristown. Its form and persistence, and its rather uniform hight, seem to indicate that it marks the strike of some of the quartzyte, although by the railroad the only rock seen was granite.

At Philadelphia the underlying rock is granite. It is exposed at numerous places in the village, and especially along the course of Indian river. The rock weathers reddish but within it is a dark gray, assuming a purplish tint.

The Potsdam quarries are on the Racket river about three miles east-southeast from Potsdam. Some of them have been worked for sixty years. At Clarkson's quarry the rock is light red or pink. It dips west mainly, at an angle of 30 deg., but on account of false bedding some of it dips more and some less, one large layer lying about horizontal. At Merritt and Tappan's quarry, which is on the river half a mile southwest from Clarkson's, we come to a deep and old quarry, formerly known as Cox's quarry, one that was running probably when Emmons visited the region. The rock here is similar to that at Clarkson's, but is marked by conspicuous color bands of light pink and brownish red, coincident with the stratification. These give the large slabs, on their broken edges, a bizarre appearance. In general the rock between here and Clarkson's quarry should underlie this. It is darker colored. But at this quarry there is a synclinal structure, and the quarrying has gone down in the trough of the syncline, to the depth of 30 or 40 feet below the surface of the river. The dip on one side is about 25 deg. S., and on the other it is about 15 deg. N. We saw at Potsdam a great variety of the sandstone quarried at Hammond, which is in the extreme western part of St. Lawrence county, southwest from Morristown. While it is all rather softer than any quarried at Potsdam, and nearly all of it white, or nearly white, like the St. Croix sandstone in Minnesota, and especially like the white (or nearly white) sandstone seen at Morristown, &c., yet there are some slabs nearly as uniformly red as the Potsdam rock, and some that are spotted in the manner of the sandstone at the falls of the St. Mary's river, at the east end of lake Superior.

At about a mile and a half below Potsdam, at the river's bank, just above the saw-mill, is a gray to white sandrock which presents an irregular surface exposure. It has been quarried to a small extent. It is mainly horizontal, and its upper layers

or its upper surface, at least, is roughened by remnants of fucoidal marks, and rusted by, apparently, rotted patches of calcareous rock, or pyrites. The total surface exposure is only about two feet, and the rusty disintegration is about three inches thick. This rock looks more like the Brockville and Morristown rock.

Three and a half miles east of Malone is Paddock's quarry, in a coarse, light-colored sandstone, which makes good, but rather fragile, flagging, worked but feebly. The rock-grain and color are quite different from the Potsdam sandstone, yet there is a light reddish tint apparent in most of it, as well as in spots. This color is deepened in shade in a manner similar to the Sault Ste. Marie sandstone, but in general is lighter than that. It is affected by false bedding in a rather remarkable manner. In this respect it is like the Potsdam sandstone at Merritt & Tappan's. The following sketch is designed to show the false bedding. The flags are rigid though only 1½ or 2

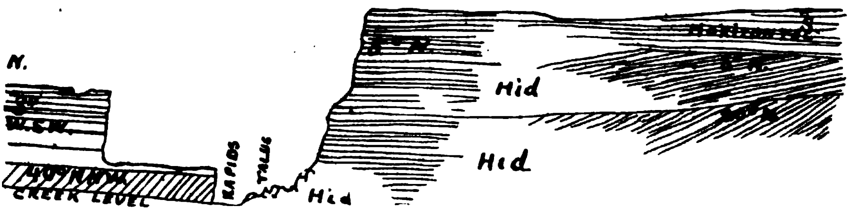


FIG. 4.—False bedding at Paddock's quarry.

inches in thickness, *i. e.* more rigid than such coarse sand-rock can usually be. The grains of quartz are not entirely compacted by cement, but there are vacant interstices. It would appear, from the false bedding, that this sediment was laid down in a very turbulent ocean, and one that was constantly cutting up and re-distributing the sediment previously arranged, but that quieter water followed the turbulence. The same rock has a slight exposure near the depot at Malone. While these strata are probably later than the strata at Potsdam, it is impossible to affirm that they do not belong to the same general age.

At Keeseville, N. Y., can be seen a conspicuous white sandstone, or quartzyte. The chasm of the Au Sable cut in this rock is narrow and in some places quite crooked. The river follows apparently a fissure or a series of fissures in the quartzyte which is also otherwise fissured and faulted, causing local dipping in different directions, and breccias at the fault lines.

Below the foot of the stairway one can walk for a considerable distance down the chasm, following a natural platform on the right side of the river. The rock shows various local changes in dip, making sometimes an apparent non-conformity between two formations. One such, which is the most remarkable, is at "the elbow," where the river first turns at a right angle. There is an appearance here of an upper sandstone formation unconformable on a lower. This idea is not weakened any by the obvious contrast in the lithology, the lower one (which forms the platform along which one walks on the right side) being very hard, finer-grained and redder than the upper, and polished by the friction of the water when the river runs over it. This polishing was noted by Emmons. At first I took this for a plane of non-conformity, but similar irregularities occur further down, some of them being in the supposed upper portion. Through a part of the distance down to the narrow place where no one can pass, the beds dip from the chasm in opposite, or partly opposite, directions, the left-hand cliff having fallen away from the rocks on the right hand, the river lying in the fissure. The strata on the left hand side, at and below the first elbow, dip conspicuously *into the left bank.* At another narrow spot, where another elbow occurs, in the opposite direction, the cause of the location of the river is seen. Just where the river turns the breccia-plane, which it occupies between the two elbows, is seen in the angle of the right bank, continuing on across the formation in the same direction, but it is blocked up and filled with the remaining rock, the cliff on the left-hand side there overhanging the breccia plane, falling on it and tightening it so as to keep the passage closed. Under such an obstruction the river, in some earlier portion of its history, had to leave the course of the fault and turn to the left, though here it also occupies another fault plane which crosses the former nearly at a right angle. Below this last turn the chasm continues, with still water, while above it the river runs with a rushing and noisy current.

At Hanawa falls, near Potsdam, a perpendicular section exposing about 30 feet appears below the falls. The right bank here seems to have two brecciated or fault planes, the strata lying about as shown by the diagram on page 104.

The gneiss and marble. At the rapids in the Racket river at Potsdam, is a peculiar gneiss, consisting almost entirely of quartz. The grain is fine and uniform in size and has a subrounded outline surface, and bands of varying composition

cross the rock surface. This banding is emphasized by greater accumulation of lichens on some than on others. The most lichenous bands are red within, when freshly fractured, and the intermediate layers are lighter, but seem to have some specks of chloritic substance. In some places this gneiss becomes mica schist, which is visible in the city. It is cut by ancient dikes of a basic rock, probably originally a diabase, which have also been subjected to some metamorphism. The dip cannot be made out.

We made an excursion westward from Potsdam to a locality known as Crary's mill, situated about seven miles from Potsdam. At five and a half miles the road crossed a creek, where at the north side of the road, appears a gneissic rock containing lenses of coarsely crystalline white marble. The marble also embraces pebbles and angular pieces of rock which is now micaceous and quartzose. Some of these siliceous pieces are banded with sedimentary structure.

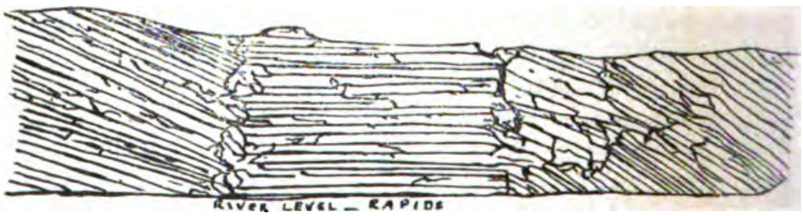


FIG. 5.—The east bluff at Hanawa falls.

At Crary's mill similar gneiss appears at the dam dipping, like the last mentioned, W. N. W. about 20 degrees. There is also here a large amount of marble which is used extensively for economic purposes, principally for quicklime. The gneiss toward the east, by the dip, must pass below the marble, which forms an extensive belt, and is traceable for several miles across the country southward. The marble is conglomeritic (but the most of it is free from pebbles), massive, colored by bands of sedimentation all dipping uniformly W. N. W. It is said to maintain this dip for six or eight miles toward the south. It appears again at the iron location of Capt. Wood, about five miles south from Crary's mill. Here the marble is associated with some verde antique and serpentine. Occasionally are seen fine alternations of red jasper and hematite in paper-thin films, but these are about the exterior portions of the iron masses, and of later origin, having no bearing on the method of origin of the ore itself. The iron is bright, pure, specular hematite, in

lenticular masses in the marble. If there be no irregularities in structure, or faults, this marble must lie below a vast thickness of gneiss, for in reaching this locality we passed, for nearly three miles—indeed all the way from Crary's mill—almost perpendicular to the strike, the dip being from 15 to 30 degrees all the way W. N. W. or N. However there may be a succession of faults, causing a reduplication of the same section. The working is small, and is abandoned, apparently from lack of a sufficient supply of ore. The dip of the marble cannot be made out, as the whole exposure is confused and rotted; but immediately north of the most northern pits is a range of gneiss dipping N. E.

At an iron exploration situated a quarter of a mile from the river, about four miles E. S. E. from Potsdam, the rock shafted is a conglomerate which, from the geographical position, is probably the bottom portion of the Potsdam sandstone. In association with this conglomerate is some red hematite, rather soft, but yet firm, as an ore, and apparently of fragmental origin. Below this conglomerate the exploration was continued by diamond drill about 50 feet, and the cores brought out, some of which still lie about the drilled hole, disclosed a serpentinous marble comparable with that seen at Capt. Wood's. The drill happened to strike no hematite in this distance, but, from the existence of the fragmental hematite in the conglomerate, and the existence of hematite in the marble, as at Capt. Wood's, it may be presumed that in the near vicinity is a deposit of hematite in the older formation from which these fragments were derived. In the immediate vicinity of such original deposits of ore, the conglomerate would naturally contain much fragmental ore, and when the conglomerate lacks such element it may be inferred there are no near sources from which it could be supplied.

Dr. U. S. Grant made a special trip to Gouverneur, and the following is the substance of his notes: At four miles from Potsdam, on the southeast side of the railroad track, is an outcrop which has an evenly rounded, apparently glaciated, form; it has the appearance of being granite, or gneiss similar to that southward from Crary's mills. No other rock outcrop was seen along the track between Potsdam and Canton. But immediately southwest from Canton, much rock exposure occurs at the crossing of the stream, and thence all the way to DeKalb. Almost all these exposures are rounded glaciated domes. In some instances a parallel arrangement of lighter and darker

bands could be distinguished in this rock from the train. The dip is about 35° northward, with a strike about N. 75° E. At several shallow cuts made in this rock it could be distinguished as gneiss of the same character as that seen south from Crary's mill. From De Kalb to Richmond are many outcrops. From Richland to Gouverneur are others that seemed to be of marble.

At Gouverneur, three-fourths of a mile southwest of the town, just on the south side of the railroad, are three large quarries in marble. This rock is of a general gray color and coarse grain, and rather indistinctly striped with white and gray irregular bands. Some of these bands are wide, so as to include much of the rock in some instances. This irregular banding is presumed to be parallel with the original sedimentation. It is the only structure shown in the rock,—not even are there any distinct jointage planes. The rock is very massive. It does not split any easier in the direction of these bands than across them. The dip is 30° N. The foreman at one of these quarries furnished the following information: "In this vicinity, especially farther southwest, and near the railroad, are several other quarries, all in the same kind of marble. The general dip is 35° to 45° toward the north, but at one quarry the rock stands vertical, with an E. and W. strike. The gneiss is found several miles N. and N. E. of Gouverneur, and also near Wood's quarry which is in marble, near the railroad, and three miles southwest of town. Here the gneiss and marble come quite near to one another, the gneiss being found a short distance south and southeast of the marble and dipping N. as does also the marble. There are three or four iron mines in the vicinity of Keene's, about 7 miles S. W. from Gouverneur, some of which are now shipping ore. They can all be reached in a few minutes walk from Keene's. The ore is generally a soft red hematite, but with some blocks of hard hematite. The ore is not in the marble, nor in the gneiss, but in a hard sandrock which is distinct from both." From the description of the ore it was understood by Dr. Grant that it is similar to that seen by him between Richland and De Kalb, as described below.

About half a mile from Richland station, northeastward, the railroad passes near several outcrops. One of these is of a hard siliceous rock holding some softer mineral. It is narrowly and conspicuously banded, some of the bands not being over ¼ inch across. The most of the bands are of quartz, and appear like bands of vitreous quartzyte. Between these are smaller

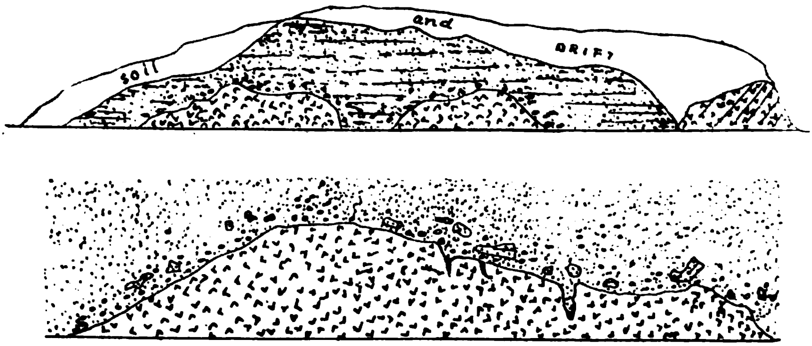
bands of quartz mixed with more or less of a rather soft greenish to whitish mineral, looking like talc, but too hard for talc. This banding appears very sharply on weathered surfaces. Aside from this banding there are no remains of clastic structure in the rock, which is holocrystalline. The rock has been bent and twisted considerably, but the average or resultant direction of the banding is about N. 20° E., and the dip is from vertical to 70° towards N. 70° W.

A short distance further, on the east side of the track, is a ridge of gray, coarse grained marble, in which are streaks of quartz rock like the last. The strike is also N. and the dip is about 60° W. At some distance still further the quartz rock above described appears again. Here the strike and dip could not be determined.

About two miles from Richland is a low cut in coarse gray marble, having bands of the quartz rock in it. Strike about N. and S.; dip about 80° E. A few rods further, on the W. side of the track is an exposure apparently the same as the last. The dip is plainly seen about 45° W. N. W.; and a little further a gneiss, similar to that seen south from Crary's mill, is seen dipping N. W. about 45°.

At three miles and a half from Richland is a cut in the marble and quartz rock. Dip not clearly seen except in one place, where it is N. N. W., about 30°. Less than 100 yards further N. E., is another cut, some 200 feet long, through a sandstone. This sandstone is of rather fine grain, more or less friable, and usually red in color, due to large amounts of hematite disseminated through it. In a few places this rock is not charged with hematite. It is then more firm, and of a yellow color, but this is in comparatively small amount. The two qualities grade into each other. The lower part of the sandstone contains rounded pebbles and angular fragments of marble and quartz of all sizes up to one foot in diameter. Just below this conglomerate is a gray, coarse-grained marble with an irregular upper surface (see figs. 6 and 7). In only one place could the dip of the marble be observed. This was at the north end of the cut, and was S. about 45°. The sandstone is broken into parallel layers which lie nearly horizontal, but in some places are tipped 10° to 15° in various directions. In two places a lamination was noted in this sandrock, running parallel with the layers, about horizontal. The lower part of the sandstone is often very compact, and apparently cemented by calcite. It has veins and pebbles of red jasper. The sandstone

grades into a soft red hematite, which appears like a good ore. The upper surface of the marble is fissured in places, and the hematitic material of the sandstone extends down into these fissures (fig. 7). Further toward De Kalb are several other low outcrops of similar gray marble.



FIGS. 6 AND 7.—Sections 3½ miles N. E. from Richland.

About one-fourth mile south of the station at De Kalb is a rounded dome of compact siliceous gneiss, mottled with red. The gneissic structure is not always present. The only dip shown is that of this gneissic structure, but in general the outcrop appears very massive.

From these observations Dr. Grant remarked that the impression left on his mind was to the effect that all the gneiss, quartz rock and marble belong to one and the same formation, though of uncertain age. It is the oldest formation seen in the vicinity of Potsdam. The marble is included in the gneiss and has gneiss both above and below it. The general strike of this formation is about E. and W. with a northerly dip of 35 deg. to 60 deg.; but there are some sudden changes both in strike and dip.

The sandstone seen between Richland and De Kalb is a much newer terrane, has been but slightly disturbed, lies on the edges of the gneiss and marble, and received debris from both in a crystalline condition, indicating that the metamorphism and tilting of the lower formations were complete before the deposit of the sandstone. The sandstone and the associated ore are undoubtedly the same as those seen about 4 miles E. S. E. from Potsdam on the east side of the Racket river, and the inference is that the conglomerate and the ore lie at the base of the Potsdam.

Other limestone. Two miles north of Norwood, on the left bank of the Racket river, are several quarries in a dark-gray, fine-grained but crystalline limestone which is spotted, in the upper layers of the quarries, with conspicuous lumps of white calcite. The rock is practically non-fossiliferous, but by considerable search, by Mr. Schuchert and the writer, we succeeded in finding some imperfect fossils, viz., fragments of some *Asaphus* and of some *Pleurotomaria*, which cannot be specifically determined, and several specimens of *Lingula irene* Bill. This rock is extensively spread in this region, and is quarried at several other places not visited, viz., at a point on the O. and L. C. railroad four miles northwest from this place, and north, at Massena springs. This evidently belongs stratigraphically above all the foregoing.

Summary and conclusions as to the stratigraphical succession at Potsdam. If an attempt be made to correlate these observations so as to express a generalized section for the northern Adirondacks, the writer would put the formations together in some such manner as follows:

1. The gneiss, containing, interstratified with it, the marble and the quartzyte, seem not to belong in the true Laurentian. Anyone familiar with the gneiss and schists which appear at the bottom of the geological scale in the Northwest would at once notice a great lithological difference. The Adirondack gneiss is more regularly and conspicuously a banded, sedimentary rock, and varies more frequently in composition; and its variations at the same time are of greater variety and greater extent. The rock is perhaps as wholly crystalline as the lowest Laurentian gneisses and schists, but there is a fresher facies, *i. e.*, an incompleted, still non-differentiated, association of minerals, and a remaining suggestion of fragmental structure permeating the rock which is not seen in the old Laurentain gneisses. Its color also varies. In the schists are rocks that are black and fine-grained, finely micaceous, but apparently carbonaceous or graphitic. They also embrace this marble, which itself is sometimes conglomeritic, and reaches a thickness of several hundred feet. In the marble is a crystalline pure hematite, in lenses that sometimes have attracted attention as valuable iron ores. The marble is sometimes siliceous, and sometimes is interstratified with quartz rock, and finally gives place entirely to a banded quartzyte. This change takes place in a direction toward the gneiss, *i. e.*, the quartzyte outcrops are between known outcrops of marble and of gneiss,

but the manner of transition is unknown. Whether the gneiss here supposed to underlie the quartzyte is a conformable member of the same formation and similar to that with which the quartzyte and the marble are associated, is unknown. It may lie non-conformably below the quartzyte, and represent a portion of an older formation, but our observations did not happen to bear upon this point. This marble, quartzyte and associated schist seem to be the northern Adirondack representatives of the marble, quartzyte and associated schists seen in the eastern side of the Adirondacks, extending with the Taconic mountains, through southern Vermont, western Massachusetts and southeastern New York and further south. Their lithology, stratigraphic order and topographic relations to the Adirondacks are similar. It is now well known that they appertain to the original Taconic of Dr. Emmons and that they have been found to contain a primordial fauna. There can hardly be a question as to their geological identity in the two regions here considered. These regions are immediately adjoining each other and must be considered as belonging to the same basin or area of deposition; with this similarity of relations to the Adirondacks coincides the fact of similarity of stratigraphic order and lithologic composition.

2. *The overlying sandstone.* The great sandstone which swings around the northern slope of the Adirondacks lies nonconformably on the foregoing gneiss, quartzyte, marble and iron ore, dipping generally gently away from the Adirondacks. The writer here is disposed to consider this entirely as one and the same formation, for taken altogether the evidence rather tends in that direction, though there is one anomalous fact which cannot be explained easily on that supposition. There has been need of constructing for the Potsdam region, if the stratigraphy there is analagous to that in the Champlain-Hudson basin, a succession of principal parts in the geological scale that will agree substantially with that made out in that basin. In the Potsdam region hitherto but one great quartzyte has been known, and no fossils have been found in it, *i. e.*, none from the rock at Potsdam, although an "Upper Cambrian" fauna is known to exist in the light-colored sandstones outcropping in the country surrounding Potsdam. The writer has been disposed to consider that the true Potsdam sandstone, or quartzyte, is more likely to belong at the horizon of the lower of these quartzytes, notwithstanding the existence of an "Upper Cambrian" fauna in the surrounding sandstones. The rather

exceptional dip and the metamorphic condition of the rock at Potsdam seemed to require its separation from the "upper Cambrian" of the region. The discovery of a persistent quartzyte associated with the limestone and schist of the region, as above stated, supplies the demand for a harmonious comparative stratigraphy, and allows of the reference of the Potsdam sandstone at Potsdam to the upper horizon. This will accord with the *general appearance* of the geological environment, as it has been generally interpreted, and will supply a representative, in the Potsdam region, of that other quartzyte which on the eastern side of the Adirondacks and further south has so often been considered Potsdam, but which really exists at the bottom of the Taconic or near the bottom of the Lower Cambrian, as the latter term is employed by the U. S. Geological Survey. This upper quartzyte varies to a nearly white rock, though even then sometimes as hard as any quartzyte, and to a red, highly ferruginous sandstone. The latter phase passes into an iron ore which is economically valuable and has been worked for ore. In this condition it is conglomeratic with remains of the underlying formations, some of the fragmental pieces being from the hematite lenses that exist in the underlying marble. It remains yet to discover the non-conformable contact of the lower quartzyte with a lower gneiss or granite, a true Laurentian formation comparable with that which lies below the "granular quartz" in the Green mountains. Should this be found by future examination in the region, nothing would be lacking to complete the stratigraphical evidence of this succession. The fauna which exists in the "granular quartz" and associated strata in the eastern part of New York, if found in this lower quartzyte and marble, would furnish the most conclusive evidence.

There remains, however, one alternative as a possible error in the foregoing conclusion. The outcrops of the quartzyte as quarried at Potsdam may not belong to the general sandstone of the region, and of this there is this evidence: (a) The rock is firmer and apparently more crystalline; its color and general grain is not remarkably different from some so-called gneiss, which outcrops below the dam in the Racket river at Potsdam, about three miles distant. In some known instances a rock resembling the Potsdam at Potsdam has been known to be converted into a siliceous gneissic rock like that below the dam. (b) The dip of the rock at Potsdam seems also to be anomalous, if that rock be in parallelism with the light-colored sand-

stones. This possible alliance with the gneiss formation would make the Potsdam at Potsdam of the same age as that of the quartzyte seen by Dr. Grant northeast from Richland.

MORRISON COUNTY, MINN.

A re-examination was made here for the purpose, chiefly of getting evidence, one way or the other, of the Archean age of the slaty schist which is seen in the Mississippi river at Little Falls.

At the rapids below the dam, at Little Falls, the direction of the sedimentary bedding is various. It is difficult to say whether it is prevailingly in any direction. Yet in one instance it was carefully measured and found to be 75° W., 3° S. by compass, the slaty cleavage being about vertical and striking S. 25° W. On the west side of the island there is a plain crumpling of the sedimentary structure and in the main a small synclinal trough, though the prevailing direction here is westerly. The lenticular, so-called crystalline masses of quartz-dioryte described by Mr. Kloos (Eleventh annual report, p. 74) are always vertical, and coincide, in their longer diameter, with the slaty cleavage. They cross the sedimentation. They are not dependent on the direction and apparently not on the character of the sedimentation, but on some later force. The same is true of some white quartz veins, as they also run with the cleavage. It is true, however, that these dioryte septaria frequent certain layers of the sedimentation, occurring in a belt parallel with the sedimentary structure, at least in one place, though individually even then they are elongated with the cleavage. This seems to show the production of quartz-dioryte in a sedimentary rock, the process being completed in certain of the sedimentary bands over small areas, forming crystalline masses, these masses being still surrounded by such materials as went to form the ordinary schist of the place. The petrographic alliance of this segregated rock with the laminated dioryte on "the point," as noted by me in the sixth annual report (p. 51), taken in connection with their elongation, and the further fact that the lamination on "the point" is parallel with the cleavage of the slates, points to the probable origination of the lamination on "the point" from the complete metamorphism of a sedimentary rock, and also to the necessary separation of the lamination structure from any dependence on the original sedimentary structure, at least in the direction

which it maintains. These nodules, when sufficiently elongated, would constitute bands resembling these seen on "the point." The production of these dioryte septaria, or dioryte bands (when elongated) seems to be favored by the occurrence of certain elements in the composition of the original sedimentary rock, since, as stated above, they frequent certain sedimentary strata, and are wanting in others.

In Gravelville in the eastern part of Morrison county, with the guidance of Mr. Robert Brown, a large granite area was visited. This rock outcrops generally on section 18, T. 41–13, and its color is red to grey, sometimes gneissic, but mainly is massive, as if formerly molten. The red is sometimes very coarse and *Scotch*-like, but also often is fine-grained and siliceous, resembling some seen on the Kawishiwi river some years ago, and also that seen at "La Framboise" place a short distance above New Ulm in 1873. In the latter case it may be sedimentary rock metamorphosed in place. This granite area runs alongside of a valley in a direction S. S. E., the valley being on the east.

In the town of Randall, on the west side of the Mississippi river, section 7, T. 130–30, greenstone is cut by the railroad. A low ridge extends S. S. W. about a quarter of a mile. The rock is fibrous-massive, and typical Keewatin. It has much calcite in spots and in veinings, also quartz, with some small pyrite cubes. This is evidently a fragmental rock, and the grains and pebbles of differing hardness stand out on the weathered surface. It is a conglomerate, of the Kawishiwin kind. The main structure stands nearly vertical but dips S. E. Numerous boulders of gabbro are strewn about here.

The rock which I visited about a mile west of Little Falls 15 years ago,* is now quarried for foundations. It appears like a modified gabbro where it lies in the streets, and when cut by the workmen, and also at the quarry, but on close inspection it is found to be a dioryte. I do not see any amygdaliodal structure, such as that mentioned in 1877.

Accompanied by Messrs. Williams and Rothwell, of Little Falls, another visit was made to Pike rapids. The rock's principal structure strikes about E. and W. and dips N. at 70° from the horizon, running diagonally across the river up stream to the left bank. At a point a short distance below the mouth of Swan river, and where the principal rock-reef causing the

*Sixth annual report. 1877, p. 53.

principal water-fall enters the right bank, is a limestone layer, standing several feet above the water, rather poorly exposed in the bank. It appears a little too far down-stream to be certainly the cause of this riffle, but the dip would certainly bring it near that position under the water. It is disconnected and cannot be traced to the riffle. It is a pinkish, fine-grained marble, marked by close sedimentary (?) structure which coincides in direction and dip with the principal structure of the staurolite schists of the place.

Near the centre of S. E. ¼ N. E. ¼ sec. 30, Town. 128–29, Morrison county, is a rather singular mica schist. This is some miles below the limestone above noted, and on the upland a mile and a quarter from the river, on the west side. The low, small ridge is situated in a swampy tract, runs about N. and S., rises about 10 feet, and apparently extends under several acres. It shows no general structure and is very fine-grained. Yet it contains occasional nodules like those in the slates at Little Falls, characterized principally by long, conspicuous black hornblende crystals which are sparingly disposed about the periphyry of the mass in a lighter colored band. In some other cases there appears to be no completion of the concretionary process, and there can be seen only a few scattered long crystals of the same mineral running at random and gathered about a point in the schist, the whole area affected being about three inches in diameter.

Lincoln, Morrison county. This is in the northwestern corner of the county, on the "cut off" branch of the Northern Pacific railroad. Here are remarkable morainic ridges, very abrupt and high, running almost like a kame, extending past the station southwest from lake Alexandria. They are remarkably abrupt and high. The region is one of red till, which extends from Little Falls to Philbrook, though beyond Lincoln the surface becomes sandy like that at Little Falls and Brainerd. These hills were only seen from the cars.

Philbrook, Todd Co. Still further northwest, at the point of junction of the Fish Trap with the Long Prairie river, an examination was made, under the guidance of Mr. Hartshorn, of Staples, and Mr. Robert Brown, of Little Falls, of the rock outcrops in that neighborhood. These outcrops, so far as could be discovered, are all of gabbro, but the rock manifests some variations which have not before been seen in the great gabbro of the region further east. It varies in patches or in vein-deposits, to a nearly white rock consisting almost wholly

of a feldspar which is striated, with a little quartz. This may be a segregation product, and not an original constituent of the mass. It also varies to a very dark and heavy trap-looking rock, which, however, still contains long cleavages of a striated feldspar. Throughout all these, except in the white feldspar, are many crystalline grains of magnetite which is probably titanic. There is also a narrow belt, not well exposed, seen below the dam of the Fish Trap in unfavorable situation for examination, where this gabbro is converted by shearing into a schistose rock, the schistose structure standing about perpendicular. In this schist, which might inadvertently be taken for an outcrop of an older formation, are still seen many of the magnetite grains, and all the feldspars as well as the hornblendes are broken and flattened. This gabbro forms a low hill range, and can be traced, according to Mr. Hartshorn, S. S. W. or nearly S. about 3 or 3½ miles, and has a width of half a mile, so far as known. It extends 2½ miles from Philbrook southerly and some distance north.

The principal object of this re-examination in Morrison county was to determine, if possible, whether the Little Falls slate be Taconic or Archean. There seem to be several strong points indicating it is of the Archean, viz:

1. The garnets and the general micaceous composition of the Little Falls slate point to its identity in age with the staurolitic and garnetiferous mica schist at Pike rapids.

2. The existence of the nodules of quartz dioryte in the Little Falls slates, and the petrographic relation they bear to the laminated dioryte at "the point," indicating a close connection in age and metamorphic transformation between the slate and the dioryte, show that both rocks have suffered a greater change through some general or regional crystallizing force than has been found in Minnesota for any strata of the Taconic.

3. Toward the eastward from Little Falls the rocks are granitic, so far as they appear above the drift, not allowing any great extension of any schists or slates in that direction, and toward the west, so far as known, all the outcrops show a more crystalline rock than is known at any place in the Taconic. It would appear as if, generally, toward the west the rocks are of the Keewatin or the Vermilion age, and that toward the east they may be of Laurentian.

4. The fine mica schist seen some miles below Pike rapids (S. E. ¼ N. W. ¼ sec. 30, 128-29) contains nodules of quartz dioryte that are indistinguishable from those that occur conspicuously in the slates at Little Falls.

5. There is therefore a general alliance between all the outcrops from Little Falls southward that requires them to go altogether into the same formation, whether Archean or Taconic. It is therefore most likely that they all belong in the mica schist belt (Coutchiching or Vermilion) of the Archean.

[*Note on the water power at Little Falls.*—Mr. M. M. Williams states that there is more water power at Little Falls than at Minneapolis,—*i. e.*, that there is more water passing over the dam at the former place. Last winter, while the water power company at Minneapolis had to shut off all leases beyond eleven mill-powers, owing to the low stage of the water, at Little Falls they were running 13-15, including wastage at the dam. The fall at the dam at Little Falls, is 20 feet; from the canals it must be a little more. At Minneapolis the perpendicular natural fall, at the falls, is about 16 feet, and by the dam and the canals, in the turbine wheels it is made to be about 52 feet. If it is demonstrated, as it appears to be, in the opinion of Mr. Williams, that more water passes Little Falls than St. Anthony falls, it is a remarkable and interesting fact, and can only be explained by supposing the water, after passing Little Falls, enters the St. Croix and St. Peter sandstones, both of which cross the river in their strike, between the two points, and both of which afford abundant artesian water at more southern points.]

THE MESABI RANGE.

At the Hale mine men have lately found (July, 1892), a soft ore at 38 feet below the surface. The rock struck at first is taconyte*, a grayish, cherty rock which is abundant on the Mesabi range, in connection with the ore. In larger quantities this rock frequently overlies important beds of hematite. It is also frequently brecciated; as a rock it varies from cherty jasper to hard ore, and in some positions it appears to have been the rock which has been changed to ore, sometimes more evidently to a hard hematite than to a soft ore. The figure below (Fig. 8) shows the geological situation at the Hale mine.

FIG. 8.—North and south section at the Hale mine.

---

* This name was suggested by Mr. H. V. Winchell, for the cherty, or siliceous, gray rock which in many places appears to have been the basis from which, by a progressive change to hematite, the ore deposits of the range have been formed. The rock has not yet received an accurate description, but is recognizable by any geologist who visits the region.

At the Cincinnati mine thirteen shafts or pits, have been sunk (March 5th, 1892), which disclose soft hematite ore. Their distribution, as indicated by the captain in charge, is shown on the small map below, figure 9, which represents section 2, 58–16. These pits vary in depth from 50 to 75 feet, and are reported to contain ore of merchantable quality ranging in thickness from five feet to fifty feet. Nos. 1, 2 and 3 struck a sand-rock, while two others, near the center of the section, encountered slates, i. e., the well-known black slate. A portion of the Biwabik mine is in the extreme N. W. corner of the section.

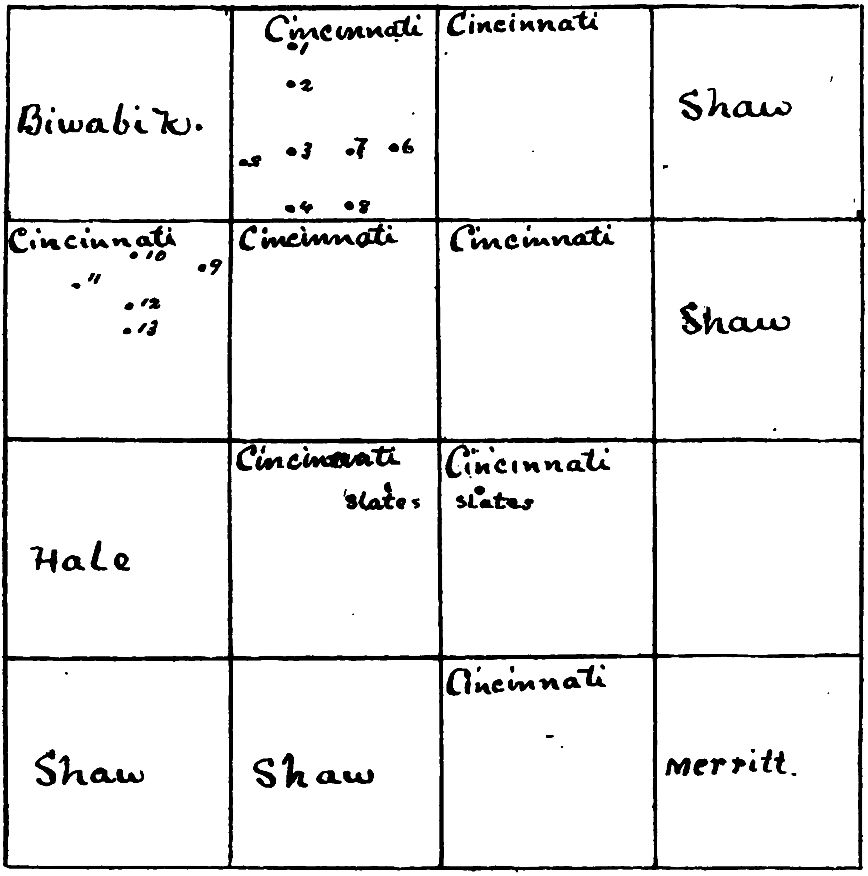


FIG. 9.—The Cincinnati mine, section 2, 58-16.

In July, when a second visit was made to the Cincinnati mine, the situation was somewhat changed. Pits Nos. 2 and 3 were extended through the ore, and the underlying rock was found to be a sandy quartzyte, rather soft, for two feet in No. 2, and

in chunks in No. 3, for two feet. Pit No. 8 was 70 feet deep. the bottom below 60 feet being in a quartzyte containing a little jasper, making a banded quartzyte. This rock is flat, with ore between the layers. It is "altogether different from the lower quartzyte." Shaft No. 3 has 45 feet of ore, and No. 2 has 35 to 40 feet. Shaft No. 4 had a bed of rock, or a bunch of taconyte eight feet in thickness lying in the ore. Shaft No. 9 went down 75 feet, with 45 feet of "paint rock" and ore alternating. Water then stopped the work. Shaft No. 10 is 100 feet deep, having mixed ore and paint rock, something like No. 9. Shaft No. 11, 300 feet west, is 65 feet deep, and has 25 feet of ore like the other, 10 feet of paint rock, 10 feet of ore, 5 feet of paint rock, lying on the quartzyte which dips 25° westward. Shaft No. 12 is 96 feet deep. Struck no rock but has 45 feet of good brown ore, and ten feet of paint rock, with ore again below. Shaft 13 is down 40 feet, and struck black slate, not worked further.

The "banded quartzyte" in No. 8 shaft on examination proves to be a form of the taconyte generally overlying the horizon of the ore and of the true granular quartzyte. The "black slate" of shaft 13 is probably the lowest part of the black slate horizon, but it is not slate, nor slaty. It is dark, nearly black, varying to greenish to grayish, a fragmental rock entirely, so coarse as to be conglomerate (1689). While very siliceous, the silica is in the form of flint pebbles, and more or less angular pieces, and a little chalcedonic silica (i. e., minutely granular like the silica of the jaspilyte). It also has rounded pebbles of a dark, softer rock, more like some of the thicker slate beds into which the slates graduate upward. Most of the rock in places is made up of these, and in finer condition they also act as cement for the coarser portions. But pervading the whole and filling the smaller interstices is black magnetite in such amount as to disturb the needle markedly.

Combining these observations with those made at Wicks' camp (May 8), the downward succession seems to be, for the rocks of the Animikie in the Mesabi range, as follows:

General section of the Mesabi range rocks.

1. Black slates, often magnetitic. Thickness unknown, but very great.
2. Conglomeratic portion of the black slates, often magnetitic (1689 and some part of No. 4 of Wicks' drill.) This is not easy separable from the next, and in some places is confused with the next, or graduates into it. Thickness may be 20 feet.

3. Taconyte horizon, mixed with ore or graduating into ore, often styled "cap-rock." Thickness 5 to 50 feet.
4. The ore horizon, sometimes encroached on by No. 3. Thickness 10 to 50 feet.
5. Fine "chalcedonic" quartzytes. In some places this is not found, but when it is present it seems to occupy, in part at least, the horizon of No. 4 (No. 6 at Wicks'). Thickness at Wicks' 17 feet.
6. Rounded, granular quartzyte. Thickness 20 to 100 feet.
7. Basal conglomerate. Thickness 5 to 10 feet.

The non-conformable underlying formation may be any part of the Archean, even the iron-bearing portion of the Keewatin; and the basal conglomerate in consequence assumes various lithology and composition.

In the bottom of shaft No. 2 at the Cincinnati is a disintegrated quartzyte (1690). The grains are angular and subrounded. There is here no jaspilyte, as at Prairie rapids, and at Gunflint lake, but the sand is stained with iron and manganese oxides. N. W. from pit No. 2, 400 feet, another pit struck "chalcedonic" quartzyte, irregular and twisted, associated with a sandstone and a conglomeratic mass, sometimes kaolinic.

Further north, 250 feet, is a pit in greenstone, and at 150 feet north of pit No. 1 is a pit in sandstone.

In general, so far as can be seen at the Cincinnati, there is a jaspilitic silica only near the bottom of the Pewabic quartzyte. A pit was seen at the Hale mine which struck the greenstone. It was all reddened by oxide of iron, but it had the schistose structure and the texture of the Keewatin; however, at the Cincinnati mine the greenstone, where struck, is still green, and unaffected by transference of iron from the upper horizon. Another pit, at the Cincinnati mine, struck a phase of the Pewabic quartzyte not often seen. The rock was greenish and hard, and fine-grained, but evidently laminated by sedimentary stratification. It had been mistaken by the superintendent for greenstone. This phase here is near the basal conglomerate, and in grain it resembles that seen at Wicks' (No. 1632), though its color is usually not pinkish. In the form of boulders it is quite common on the surface, weathering nearly white, so as to resemble marble.

The rock taconyte prevails along the eastern part of the the Cincinnati, and probably in the eastern part of the section, the ore becoming more and more abundant in the western pits. There are so many pits scattered through this region that it gives the impression, the rock and dip being uniform, (with one

exception), that the ore originated from a grand change in the taconyte rock toward the west. Further observation, however, is needed, to demonstrate this.

The Biwabik mine. The adjoining figure shows the three "forties" on which this mine is located, and the positions of the various shafts here mentioned, as they appeared July 19, 1892.

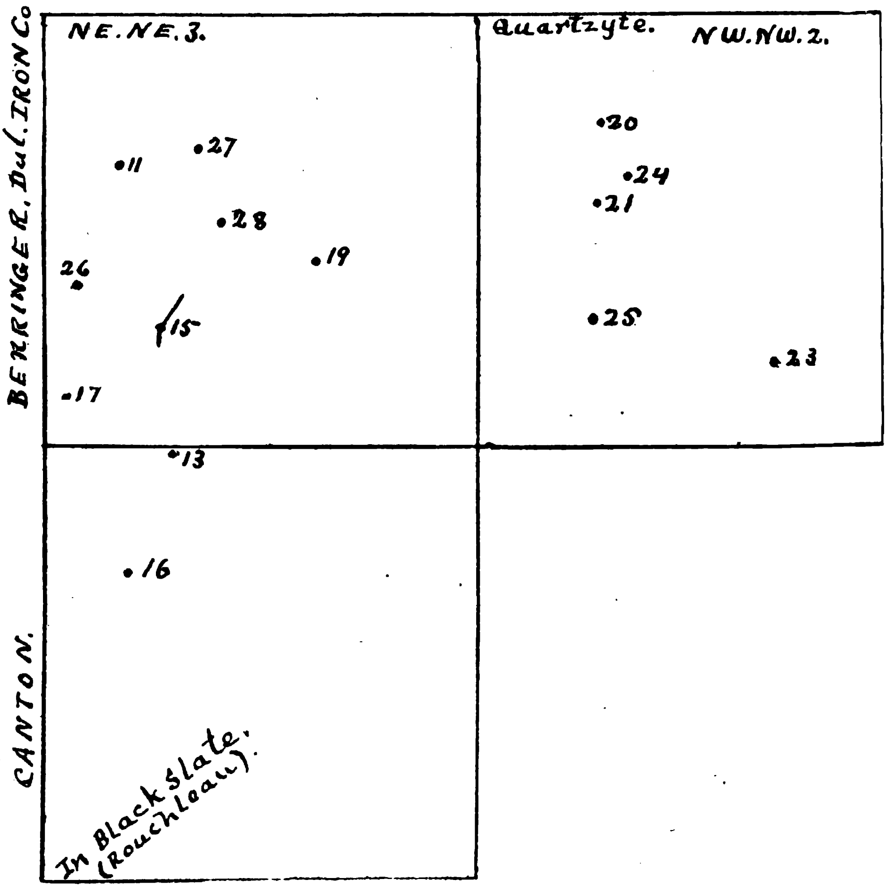


FIG. 10.—Map of the Biwabik mine, July 19, 1892.

Shaft 13 has the following section: surface, 36 ft.; paint rock 18 ft.; mixed ore and paint rock, 34 ft.; purple paint rock (56 Fe.), 8 ft.; yellow ochre, 4 ft.; total, 100 ft.

An average analysis of ores from shaft 13 was made by E. E. Brewster, with the following results. This included the upper "paint rock," and "mixed ore and paint rock." Iron, 50.05; Phosphorus, .049. The upper paint rock alone gave: Iron, 46.10; Phosphorus, .041; Silica, 14.44, being still a bessemer ore.

Shaft 15 has the following section: surface, 30 ft.; paint rock, 13 ft. (44 p. c. Fe.); yellow ochre, 7 ft. (62 p. c. Fe.); blue and red ore, 7 ft.; soft blue ore, 27 ft. (67 p. c. Fe.); brown ore, 22 ft., limonite (63.20 p. c. Fe.) Stopped here on account of water. At the depth of 85 ft. a drift was in "soft blue ore" in a N. E. direction, and another was run south. The former was extended 150 ft. from the shaft, and the latter 45 ft. They only found the same ore as at the shaft. Five hundred tons of the blue ore were taken out, and now lie in the stock pile. An average analysis of the ore in shaft 15 gave Messrs. Rattle and Nye 66.5 of iron, and E. E. Brewster, 65.40 Fe., .034 Ph. The complete analysis from shaft 15 gave the following result, by W. E. Rice, of Newcastle, Pa.:

Metallic iron	69.054	Alumina	.300
Silica	1.340	Manganese	.130
Phosphorus	0.168	Magnesia	.072

Shaft No. 17 has the following section; surface 28 ft.; paint rock, 16 ft.; yellow ochre (some brown ore), 17 ft.; blue and brown ore mixed, 46 ft. An average analysis from this shaft was made by E. P. Jennings, Hurley, with the following result; iron, 63.25; phosphorus, .032.

Shaft 19 has the following section; surface, 52 ft.; mixed surface and ore, 2 ft.; brown ore, 12 ft.; "sand," 2 ft.; soft ore, (blue and brown), 6 ft.; soft blue ore, 12 ft.; brown and blue ore (hard), 6 ft.; soft blue ore, 13 ft.; brown ore, 2 ft.; total, 107 ft. This entire shaft is dry.

An average analysis by Brewster from the first 20 feet in shaft 19, gave the following result: Iron, 64.35; phosphorus, .045. The next ten feet gave, iron, 65.95; phosphorus, .047.

Shaft No. 20 has the following section; surface, 5 ft.; brown ore, 19 ft.; hard blue ore, 11 ft.; brown and blue ore, 6 ft.; hard brown ore, 10 ft.; soft brown ore, mixed with some blue, 17 ft.; brown ore, 1 ft.; stopped, no water. Analyses (average) from this shaft gave Brewster: first 15 feet; iron, 62.40; phosphorus, .065. The next 10 feet gave iron, 62.40; phosphorus, .068. The next 10 feet gave iron, 63.30; phosphorus, .068. The next 10 feet gave iron 58.65; phosphorus, .104, and the next 10 feet gave iron, 60.20; phosphorus, .081.

Shaft 21 has the following section; surface, 6 ft.; brown ore and yellow ochre, 20 ft.; hard blue and brown ore, 5 ft.; soft blue ore, clean, 8 ft.; brown and blue ore, 4 ft.; soft blue ore, 10 ft.; brown ore, 10 ft.; blue and brown ore, 7 ft. Stopped, no water.

Average analyses by Brewster gave the following results from this shaft:

First fifteen feet,	Iron, 50.85;	Phosphorus, .097.
Next ten feet,	Iron, 62.50;	Phosphorus, .063.
Next ten feet,	Iron, 63 45;	Phosphorus, .029.
Next ten feet,	Iron, 62.25;	Phosphorus, .051.
Next ten feet,	Iron, 63.45;	Phosphorus, .038.

Shaft 21 has 56 feet of ore, varying from blue to brown, excepting five feet of taconyte, the brown being about three or four feet at the bottom. This shaft apparently also has a bed of soft manganese at the depth of 94 feet.

Shaft 24 has a "surface" of 29 feet, and about 50 feet of blue ore, brownish at the bottom, still sinking.

Shaft 25 is a repetition of shaft 13, with the exception that a blue ore appears below the yellow ochre, at the bottom, and the ochre was found to be 13 feet thick. This gives reason to expect that the blue ore of shaft 15 will yet be found below the bottom of shaft 13.

Shaft 26 has the following section: surface, 23 ft.; yellow ochre, 10 ft.; brown and blue ore, 4 ft.; soft blue ore, 31 ft.; brown ore, 2 ft. (just touched); total, 70 ft.

Analyses were made from this shaft with the following results:

First ten feet in ore,	Iron, 60.65;	Phosphorus, .043.
Second ten feet in ore,	Iron, 64.70;	Phosphorus, .042.
Third ten feet in ore,	Iron, 66.55:	Phosphorus, .025.

It is noted by Mr. Jones that there is a body of soft blue ore of highest grade, between two beds of hydrated ore, as shown in all the sections.

Near the town line, in the extension of the line between sections 2 and 3, a shallow pit struck green siliceous rock, evidently a part of the quartzyte. It is similar to the greenish schists and slates lying south of the quartzyte foot wall at the Aurora mine on the Gogebic range.* It is a slaty, gray quartzyte, in part, brittle and sharp, and in part it is soft, greenish and largely made up of debris from the underlying greenstone, with sericite and argillyte. Much of it cannot be called quartzyte. However, it is apparently nearly on the horizon of the fine-grained phase of the quartzyte seen at Wicks'. Here it is below a coarser sand rock, but at Wicks' it was reported by Wicks to be above the principal mass of coarse sand rock.

*Compare 16th Report of the Minnesota Survey, p. 58.

The following complete analyses was made of the Biwabik ore by Frank D. Crolaugh (Stewart Iron Co.):

Iron	66.864
Phosphorus	.009
Alumina	.840
Silica	.880
Lime	.041
Manganese	.100
Sulphur	.030
Magnesia	.021
Loss at red heat	2.000
Titanium	None.
Arsenic	None.
Copper	None.
Chromium	None.

The Biwabik apparently has ore on three-fourths of two forties, an average of 50 feet thick. Allowing ten cubic feet for one ton of ore, the amount of ore "in sight" is found to be 9,905,000 tons. This is a conservative calculation. The ore is often 60 feet thick, and even, in one case, 68 feet in thickness, and there is great probability that the ore underlies more than one and a half forties. Mr. Jones, under whose guidance the foregoing facts were ascertained, estimated the total ore "in sight" at *eleven* millions of tons, and others have made it as high as twenty-three millions.

The Chicago mine is on sec. 4, 58-16. The land of this company is outlined on the following sketch map, fig. 11.

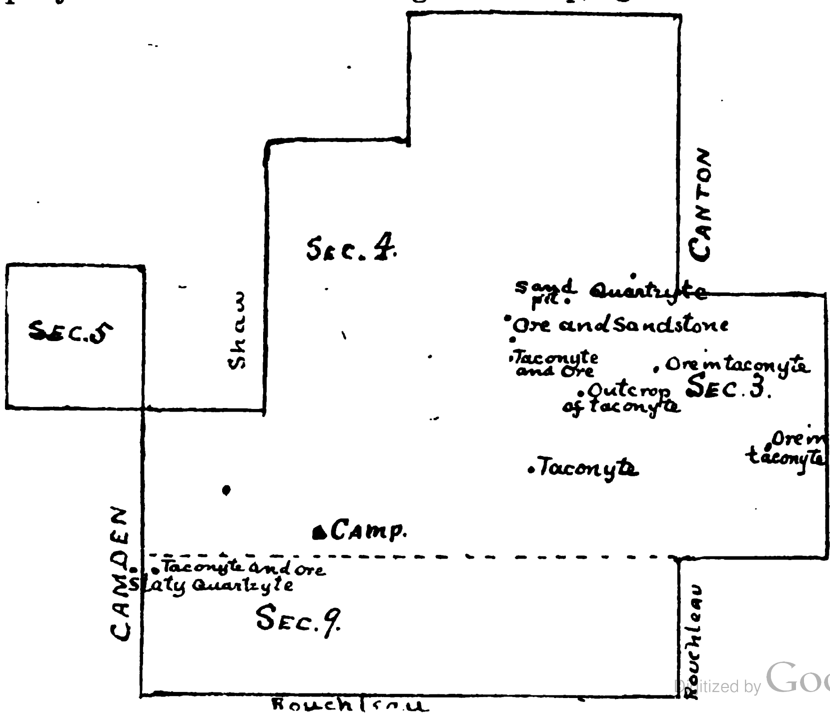


FIG. 11.—Outline map of the Chicago Co.'s land, July, 1892.

The Chicago company's land was visited July 20 and 21, 1892, and the examination was made under the guidance of captain Johnson. It was a pretty thorough examination, all the trial pits and shafts having been visited. On the accompanying figure a few of these pits are shown, viz., such as were important as to some geological features disclosed. The only ore body found is near the eastern side of the property, where nine feet of good, soft, blue ore was found in a pit. It lay within the taconyte rock, having:—

Surface	15 ft.
Taconyte	17 ft.
Taconyte, with ore in lumps	10 ft.
Soft, blue ore	9 ft.
Taconyte	12 ft.

But this shaft was abandoned at 63 feet because there was no return of ore on going deeper, and because the shaft had not been well prepared for working deeper with safety. At a later date Mr. Johnson reported that he had begun a drift in this shaft at the level of the ore, about 50 feet below the surface, and he found the rocks dipping at an angle of about 30 degrees toward the west, and that the ore apparently was increasing in amount.

In the course of the examination of this tract it was observed that the taconyte comes close upon the quartzyte, in separate pits, with little or no ore, at least in some places. This occurs at the eastern and western extremes of the property, and there is nothing shown by the intervening pits to indicate any probability of a change. This examination also tends to establish some principles respecting the ore bodies.

1. The soft ore occurs in the midst of the taconyte rock, though I had believed that it occurred, when in considerable amount, first at the bottom of the taconyte.

2. The taconyte is separated from the quartzyte by a thin stratum of hard brown ore.

3. There is a stratum of hard, fine-grained quartzyte, similar to the pinkish quartzyte at Wicks', embraced in the basal quartzyte (1696). This seems to be the same as that detected at the Cincinnati and Biwabik mines.

4. The first phase of the quartzyte below the ore is coarse and rather loose, as at the Colby and Aurora mines on the Gogebic range.

5. It is fine-grained, becomes slaty and sometimes apparently sericitic, but hard and brittle, at a lower level. In this

condition it is gray or green, and might be styled novaculyte, similar to that lying below the mass of quartzyte at the east end of Teal lake at Negaunee.

6. The rock all about the Chicago property is nearly flat, and is unfavorable for the progress of the change which has been supposed to have produced the ore, and so far this rather confirms that hypothesis.

The McKinley mine, July 21, 1892.

On the accompanying sketch map the various shafts and pits, as referred to here, are located. Many others which revealed nothing important are not noted.

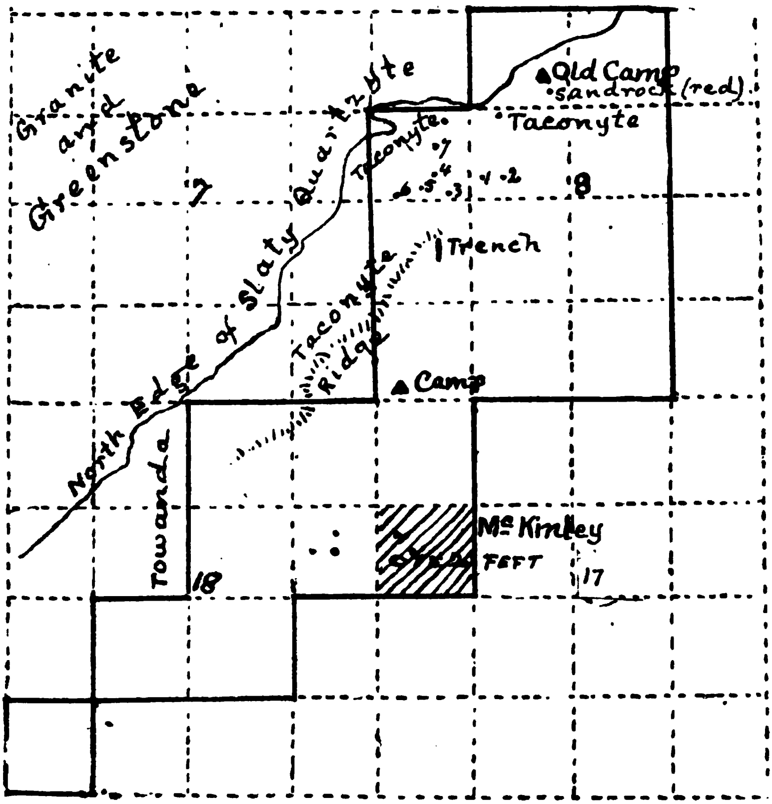


FIG. 12.—McKinley mines.

Pit No. 1, the first one sunk, has 18 feet of ore, with no taconyte overlying. It is 40 feet deep and stopped in the ore body.

Pit No. 2 passed through the hard pan down to the ore. No capping; 42 feet deep.

Pit No. 3. Surface, 7 ft.; capping, 5 ft.; ore, 57 ft.; stopped in ore; much water at the bottom.

Pit No. 4. Surface, 11 ft.; mixed ore and taconyte, 29 ft.; ore, 25 ft.; still in ore; much water.

Pit No. 5. Surface, 20 feet; capping, none; ore, 30 feet; taconyte, 12 feet; ore, 1 ft; expect to resume.

Pit No. 6. Surface, 60 ft.; ore, 8 ft.; incomplete from bad weather; will resume.

Pit No. 7. Surface, 12 ft.; broken taconyte, 28 ft.; no ore yet.

At the "old camp" a well struck a "red grindstone rock," but no samples were preserved. It may be a rusted condition of the Pewabic quartzyte, or it may be some Cretaceous sandstone.

The map shows the line of strike of a taconyte body, the outcropping bluff facing north and running northeastwardly, and below it all the ore thus far found in section 8 has been found. At the present camp (see fig. 12) a well was dug in black slates 8 to 10 feet. The well is 32 feet deep.

On some of the McKinley land the black slates appear, and at the well at the new camp, they give a water carrying sulphuric acid, evidently derived from the oxidation of pyrite, which is in the slates in crystalline form. In a pit further north the rock, which is apparently of the black slates, is somewhat different, resembling some of the so-called ash-beds of the Cupriferous.

The ore pits south of the camp, near the townsite of McKinley, are probably all above the main ore body. It would require some unexpected break or irregularity in the strike of the taconyte, to cause the appearance of considerable ore deposits in that locality, as the surface is probably not only above the ore body but also above the main taconyte mass. It is the opinion, however, of Capt. Hill, that there may be important ore deposits on the present townsite. It was reported that a bed of 20 feet of ore had already been discovered in this vicinity and that it was likely that the townsite would be changed to some other place. On examining this ore it was seen to be quite different from that known to occur at the lower horizon. It is lean, hard and soft (ochery), mixed with some green clay, some slaty portions, some magnetitic, and altogether as yet non-merchantable. It may be possible to get a bed of ore in there, but as it would be on a new and higher horizon, it would be a new thing and indicate a great increase in the possibilities of the range.

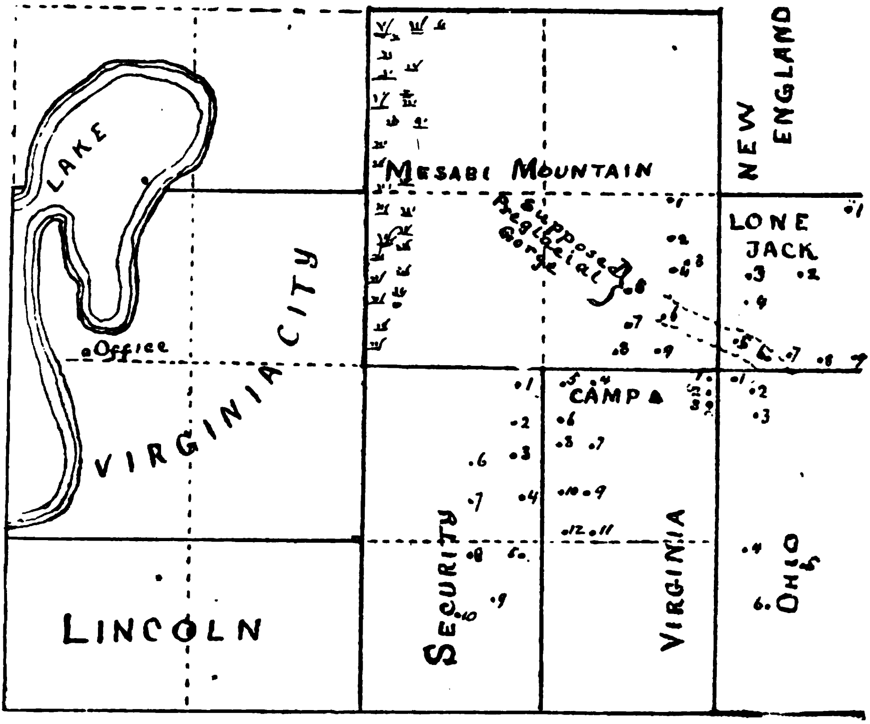


FIG. 13—Mesabi Mountain, Security, Virginia; sec. 8, T. 58-17.

Mesabi Mountain, Security, Virginia, etc.

The accompanying sketch shows the relative positions of these properties, and some of the pits that had been sunk to July, 1892. Here the dip is reversed from that usually met with on the Mesabi range. The rock bearing the ore lies on the N.W. slope of a greenstone ridge, which is a spur of the general greenstone area further north, and has a N.W. dip, varying from N.W. to 12 degrees south of west, amounting to 5 to 15 degrees. In the axes of these ridges granite frequently is found to take the place of greenstone. In sections 15 and 14 the bluffs of Pike river are precipitous and high with cliffs of greenstone, the precipitous cliffs usually facing E. and S.E. The same kind of surface is in sec. 29, in the same town. From some of these hills of greenstone it is reported that the eye controls a vast country toward the south.

In this region some interesting observations were noted. Mr. W. J. Merritt, who is in charge of the Mesabi Mountain property, is of the opinion that the main ore deposit lies above

the taconyte rock, thus agreeing with some evidence tending to the same conclusion already noticed at the McKinley mine This opinion is based on some general observations made by him on the geographic relations of those trial pits in which ore has been found compared with those which do not contain ore, but have encountered the rock taconyte.

The following notes describe the pits represented on fig. 13.

First, Mesabi Mountain.—As given by Mr. Merritt or his superintendent, pit No. 1 encountered taconyte after passing through three feet of good ore; pit No. 2 struck what is known as taconyte and to which was given the local designation "stove-plate rock" by the workmen; it was very ferruginous and resembled ore, but in thin and brittle sheets; pits Nos. 3 and 4 encountered a fine blue ore; pit No. 5 struck red ore; pit No. 6 encountered a peculiar irony gravel, supposed by the superintendent and others to be from an old pre-glacial gorge cutting the iron ore beds; pit No. 7 encountered a black ore, good quality, and No. 8 had blue ore.

Some of these pits are from 50 to 75 feet deep and have, sometimes, 50 or more feet of nice clean ore.

The supposed glacial gorge represented on the sketch map (fig. 13) passes from the Lone Jack property onto the Mesabi Mountain, and is considered to be a very uncertain hypothetical explanation of the existence of certain gravel. It may be that there is a gorge in the rocks running about as supposed, but the gravel may be of Cretaceous age rather than post glacial. The gravel itself exhibits every feature of a promiscuous fragmentary accumulation. Some of it is completely made up of ore like that of the region, but of rather low grade, and some of it is apparently derived from a rock but little affected by ferric oxide. It seems to vary exactly as the rock of the country does, that is, it is "lean" or not, and its different constituents can be referred entirely to the country rock adjacent. The further phenomena of this gorge will only be revealed by the mining operations that are sure to follow. At the present time this gravel is simply overlain by the common till and graduates rather abruptly upward into an irony till and then into a gray till. The pebbles are cemented together by a coating of ferric oxide deposited on them since they were placed in their present position, indicating the later supply of some water, in large amount, capable of parting with iron oxide. Some of the pebbles have an irony crust harder than the interior, and from the crust toward the center there is an increase

of coarseness of texture, even becoming somewhat spongy, indicating some progressive change from the circumference toward the center, the whole pebble, however, becoming good Bessemer hematite; but such pebbles are not common. The great mass of the gravel, some of it being coarse as walnuts, consists simply of very irony rock of some sort, of very uniform grade throughout. It does not appear that the gravel has become ferruginated to any great degree since its deposition as gravel. The ferruginous surface film is nothing more than such as might be found on any exposed surface over which the waters of this region might pass.

In the Lone Jack property in one pit the gravel was found to be 35 feet, and below that a fine blue ore, continuous to a total depth of 102 feet. The other pit has gravel ore 66 feet and goes no deeper.

Second, Security.—Two lines of trial pits had been run by the superintendent, J. M. Huggins, north and south across the north forty of this property, which revealed some interesting facts as to the relations of the ore to the rock taconyte. The second series also extends over onto the south forty. The eastern series includes the following pits from 1 to 5 inclusive. In these pits a large body of purple ore has been developed at a short depth below the surface. The other series, which lies further west, including 6, 7, 8, 9 and 10, encountered generally nothing but rock, though in some cases overlain by ore, reaching a thickness of 6 to 9 feet; yet in No. 9, which really lies further east than the rest, Mr. Huggins reported that he found an alternation of good ore and taconyte, about one-half being ore, the beds of which were one to two feet thick. At the pit No. 10 of this series careful measurement was made of the dip of the taconyte, the result being 10° to 15° west, 10° north, by compass.

The facts seem to show, so far as the Security property is concerned, that the strike of the ore and rock is about north and south, or a little northeasterly, and that the main ore deposits are stratigraphically below the taconyte. It seems, however, that the ore is not entirely below the taconyte, as shown by pit No. 9, but it is interbedded with it. It also appears by the depth of the pits in the western series that the main body of ore ought to have been struck there if it maintains a stratigraphic relation below the taconyte. Upon the whole it is unsettled whether the ore body runs below the taconyte or re sults from a change in the taconyte.

Third, the Virginia.—While there was a series of pits along the western side of the north forty (see fig. 13), evidently striking the same body of fine ore as revealed on the Security next west, the whole dipping west northwest, yet there was another belt of rock disclosed by a still further eastward line of pits, which apparently belongs near the bottom of the ore body and manifests about the same uncertain stratigraphic relations as the taconyte on the Security. It was the occurrence of this body of rock, which was taken by Mr. Merritt as the stratigraphic equivalent of the taconyte and the existence of ore above the taconyte on the Security, that induced him to regard the ore-body as generally stratigraphically above the taconyte rock. But it is probable that this is not the stratigraphic equivalent of the taconyte, but lies below it. This rock is a marked and persistent stratum; it cannot be called taconyte; it is a hard ore, or impure jasper conglomerate ore and furnishes many boulders that lie all over the surface in this country; it as certainly lies below the main ore deposit at this place as the taconyte further west lies above it. This stratum was struck in pits 7 and 9. The dip on the Virginia was reported to be 12° to 15° west, 10° south.

From pit No. 12 on the Virginia was thrown out a large amount of kaolin, the whole thickness being 16 feet. This kaolin is in the midst of ore, which lies both above and below it. This ore and kaolin are intimately associated; they make blotches in each other. The kaolin has apparently a sedimentary structure agreeing with that of the rocks of the region, and the hematitic interlaminations in the kaolin are very marked. When the kaolin is massive and coarse and nearly white, it contains balls and lenticular masses of silica. These balls are in both the kaolin and in the red and hematitic portions, which seem to be kaolin stained with ferric oxide. They have a uniformity of position, being elongated in the same direction. There is usually an abrupt transition between the white and red colors, but aside from the presence or absence of ferric oxide there is no apparent difference in this kaolin.

To further establish the relations of the ore to the taconyte, a special exploration was entered upon by Mr. J. W. Merritt, of the Mesabi Mountain Iron Co., and Mr. P. W. Scott, of the New England and Virginia mines. The former has begun to sink a shaft in the taconyte with the view of going through it or deep into it (pit No. 2 of Mesabi Mountain); and the latter has sunk three trial pits near the mutual limit between the ore and the

rock, as detailed below. This last trial has demonstrated that the rock is actually converted, on the same stratigraphic plane, into ore. The facts are as follows, and they can be illustrated by figures 14, 15 and 16:

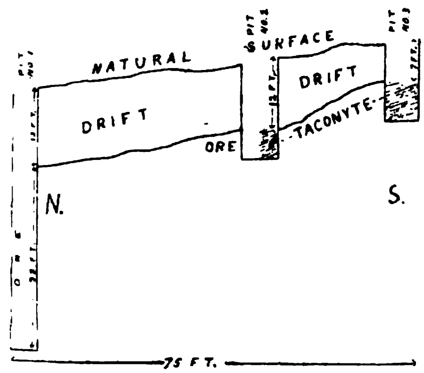


FIG. 14. A perpendicular section through three pits adjacent to each other, north and south, on the Virginia.

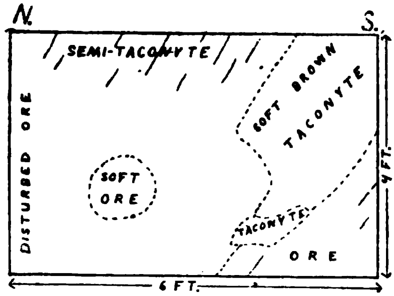


FIG. 15. Plan of the bottom of pit 2.

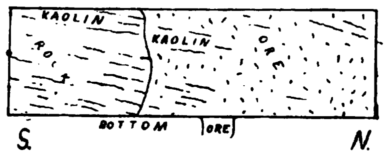


FIG. 16. Portion of the west side of pit 2 at the bottom.

On the sketch map (fig. 13) may be seen the location of these three trial pits, numbered 1, 2 and 3, on the Virginia property. Pit No. 1 of this series encountered black ore in large quantity at the depth of 13 feet below the surface, the ore being found to be at least 33 feet thick. Numerous other pits in the immediate vicinity had gone deep in good blue ore, one being the deepest in the ore yet sunk on the range—102 feet; others were so near an area of taconyte rock that it appeared easy, by one or two intervening pits, to develop what relation exists between the ore and the rock. There is a distance of 75 feet between pits 1 and 3 (see fig. 14.), the former being further north and 46 feet deep, with 33 feet of good, clean, black ore, and ore still deeper; the latter but 7 feet deep and on the ledge. Then pit No. 2 was sunk at 50 feet from No. 1; this one struck the rock at 12 feet, dipping, as in No. 3, about 10° or 12° N. N. W., or toward pit No. 1. In this pit (No. 2) rock exists on the south side and ore on the north side (see fig. 15). There is an indistinct trace of the sedimentary structure in the form of a thin white kaolinic sheet running from the rock well out into the ore; but in general the ore part is disturbed and sunken down from the rock. There are irregular pockets in

the rock, consisting of ore, connected with the main ore body, but the bottom of the pit is almost wholly in ore. The kaolinic sheets of the rock remain white and distinct as such—even in the otherwise changed rock—and show that the kaolin antedates the ore as a native element in the formation. Messrs. Scott and Short both went down with me into this pit, and with pick and hammer we made close examination. The outlines of the rock on the bottom of the pit and its appearance on the west side of the pit are represented in figures 15 and 16. Some specimens were taken from the line of junction of the rock and ore, showing distinctly the rather abrupt change between them, the sedimentary beds being continued from one part to the other (1707). This was of a rather soft ore and a rather soft rock.

Mr. L. W. Ayer, who was much interested in this trial, subsequently wrote the following report as to further developments.

MESABI MOUNTAIN CAMP, Aug. 7, 1892.

PROF. N. H. WINCHELL, MINNEAPOLIS, MINN.

DEAR SIR:—Agreeably with my promise to keep you posted as to the results of the work in the pit No. 2, on the Virginia property, in the N.E. corner of the N. E. ¼ of S. E. ¼ sec. 8, T. 58, 17 W., I beg to report as follows:

On the 28th ult., the day you left here, the pit was twenty feet deep with fourteen feet surface clay and boulders, then taconyte apparently in transformation—the half of the pit toward the northwest or toward the ore bed being mostly good ore, though generally of low grade, and running into the taconyte in almost imperceptible gradations.

In the next four feet the relations continued about the same, the ore a little better perhaps.

In the next two feet appeared a comparatively high grade soft ore mixed with a light colored quartz sand.

Next eighteen or twenty inches—thin layers of hard ore, low grade, one and a half to two inches thick, alternating with sand. When blasted this ore broke into small fragments from one to three inches, with rectangular faces.

From this depth (about thirty feet) to the bottom of the pit, a depth of thirty-five feet in all, was quartzyte, very slightly "banded" by streaks of iron.

The property having in the meantime been leased, the original intention to put the pit down to determine the thickness of the rock and the question of an ore body under the rock was abandoned, and the pit left as above stated at a depth of thirty-five feet, with the connected problems still unsolved.

The appearance of the pit when you were here very strongly supported the replacement theory, and I was nearly a convert, but the later developments make the matter look uncertain again.

* * * * * * *

Yours very truly, LYMAN W. AYER.

It would appear from Mr. Ayer's letter that the location of pit No. 2 was such that when the rock was first struck it revealed the line of transition from rock to ore, yet on being sunk deeper disclosed only unchanged rock or nearly so. It is evident, therefore, that the line is a zigzag one and that the further developments do not throw any doubt upon the conclusions indicated at first. Had the workmen followed the rock lying to the north, instead of going perpendicular, they doubtless could have kept the line of transition within sight.

The following figure (No. 17) is intended to express, so far as revealed at this visit, the areas of three taconyte bodies separated by ore bodies, both lying nearly horizontal. It is not possible that such a relation could exist without a local change of the rock of the country to iron ore. It remains yet to discover what was the original rock and what were the causes of its transformation.

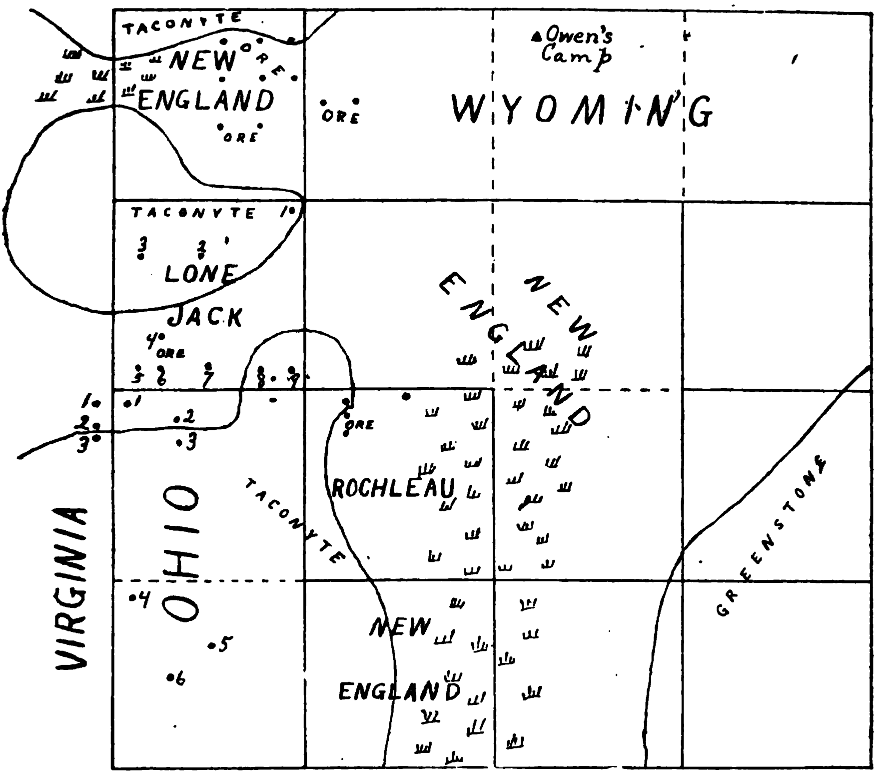


FIG. 17.—Three atocnyte areas in sec. 9, T. 58, 17 W.

In the midst of these interesting developments the writer made a summary of the facts developed on the Mesabi range

touching the problem of the ores of the range, and read the paper before the American Association for the Advancement of Science.* Subsequently this paper was printed in full in the American Geologist, †as follows:

SOME PROBLEMS OF THE MESABI IRON ORE.‡

N. H. WINCHELL, Minneapolis.

CONTENTS.

Perhaps there is no more important or more interesting question, at present debated, relating to the iron ores of the Northwest, than that of their origin and their stratigraphic relations. From an economic standpoint, no less than from a scientific, there could be no more important question, for it is not until the geological relations and origin of these ores are understood that proper methods of mining them can be entered upon, and with the least expense. It is because of recent studies in the field, adding some new facts to the solution of this problem, or complicating it by the injection of some new conditions, that the writer desires to review the elements of the problem and to show the difficulties that yet lie in the way. It will be well to enumerate briefly the hypotheses that have been propounded recently, as an introduction to this discussion. There are five.

*Rochester meeting, 1892, p. 176.

†Vol. X. pp. 169-179, Sept., 1892.

‡Read August 22, 1892, before Section E, of the American Association for the Advancement of Science, Rochester, N. Y.

1. *Substitution for limestone.* Microscopic examination revealed the existence of remnants of calcite, or dolomite, in some of the "cherts" accompanying these ores in some places, and after long research the late professor Irving arrived at the conclusion that the whole body of the ore horizon was originally in the form of a limestone essentially a "cherty carbonate," simulating, in origin and essential characters, the black-band ores of the Carboniferous. This inferentially led to the idea of a great primordial carboniferous age.

2. *Substitution for carbonate of iron.* Owing to the frequency of such a change observed in nature, it was but a short step to suggest a carbonate of iron instead of a carbonate of lime. This would more readily supply the iron, which must be explained, than carbonate of lime, and at the same time would only require a slight change, if any, in the nature of the original rock, and in the conditions of its deposition.

3. *Concentration of iron oxide from the decay of ferriferous schists, or other rock.* When rocks decay, it makes but little difference what they are, they part with their contained iron. It may go off in solution, if the proper acids be present, and be gathered as oxide under ordinary natural drainage and weathering, in considerable quantities, on the evaporation of the solvent at some lower level. This process has been suggested as the possible cause of the accumulation of these ores at the stratigraphic horizon where they occur.

4. *Accumulation in troughs formed by dykes cutting tilted strata at a somewhat uniform inclination*, the iron itself being supposed to have been carried down and deposited by ferriferous waters, replacing a supposed "cherty carbonate." This hypothesis involves the same conditions and processes as No. 1 above, but also gives explanation of the location of the supposed ore lenses. At the same time it involves the decay and concentration in a definite rock horizon which is demanded by No. 3.

5. *Deposition from oceanic solution at the time of the formation of the rocks associated.* That the iron ores of the Keewatin age were deposited from solution, has been inferred from their association with rocks whose composition requires the cotemporaneous action of eruptive forces—but which are stratified by oceanic agency—such eruptive action causing chemical reactions that would result in the precipitation of iron and silica. This hypothesis has been applied by the writer also to a portion of the Mesabi ores, viz., such as are embraced as some-

what irregular (wandering) strata in the lower portion of the formation. Such may be either hematite or magnetite. It may perhaps be extended farther than has been proposed.

Some facts of the manner of occurrence.

The Mesabi iron range extends, within the limits of Minnesota, a known distance of more than 150 miles, and it is iron-bearing through its whole extent. It commences at the west end of Gunflint lake, on the national boundary, and has been partially explored southwestwardly as far as the Mississippi river near the falls of Pokegama. The iron horizons do not fluctuate in their stratigraphic positions. The iron varies as the character of the accompanying rock varies. It is a duplex range and embraces ores of two distinct origins and kinds.

The more southerly portion of the range, which is made up of gabbro hills, contains large deposits of titanic magnetite, and this may be dismissed with the statement that this ore is at present not used, and of little economic concern. This discussion appertains wholly to the more northern belt where the recent remarkable developments have been made. This northern belt embraces non-titanic magnetite and hematite as well as limonite and gœthite, or "yellow ochre," as it is sometimes denominated by the miners. The magnetite thus far discovered is not of economic importance, compared with the hematite and gœthite, but there are explorations now being made in some of the magnetites which promise to become perhaps equally valuable with the hematites.

The non-titanic magnetite is found in the eastern portion of the range and at a lower horizon in the strata than the hematites, and when it is represented in considerable amount there is little or no hematite in commercial quantities. It is sometimes in close asssociation with the gabbro containing titanic magnetite, and it is a reasonable hypothesis to refer the magnetic quality to the effect of the heated gabbro on the original ore, concentrating the iron by the expulsion of some of the oxygen. Still there is a trace of magnetic ore further west. It is there found in lean iron-bearing rock, and occupies belts of a few inches which pass through the rock in a rather peculiar zigzag or wandering fashion. But still further west the Pewabic quartzyte, which is the horizon which holds the magnetite in the eastern end of the range, is again regularly interstratified with magnetite in considerable amount, and as such it has been explored for commercial uses.

Hard hematite is found in the Mesabi range, but it is rather as an accidental appendage of the soft hematite, and usually it grades into low-grade ore and is discarded.

Hard limonite is found in larger quantities than hard hematite. It is apt to be impure, and it occurs in somewhat the same manner as the magnetite—*i. e.*, it branches and permeates a rock bed irregularly, though frequently seen in distinct nodules and in vugs when it is found to be a valuable ore.

The hydrated oxide, however, in the form of gœthite is quite abundant. Some shipping mines will depend largely on this ore. The ore is in the form of ochre-yellow powder, or small masses easily reduced to powder. It is found only in the region of the recent new developments, in the western portion of the range.

Soft hematite, however, is the ore for which the "Range" will be celebrated. This has recently been discovered in indefinite and almost incalculable amounts. It is generally amorphous, but in lumps, frequently as if a breccia of some sedimentary rock, easily crushed, and it also exists as a granular powder, finer than mustard seed, and can be mined by the simplest methods. The plans now being entered upon for excavating it only require a steam shovel and a railroad train.

Stratigraphic relations.

The horizon in which this ore occurs is that which has been identified as Taconic, or primordial. The strata have a gentle dip toward lake Superior, and a uniform strike from one end of the range to the other. The strata are as follows in descending order, omitting minor variations.

1. Black slate with interbedded sheets of eruptive materials which are widespread and non-amygdaloidal.

2. Gabbro out-break. Titanic ore horizon. The line of this outbreak is found not to follow the present northern strike of the hematite ore horizon, but to encroach upon it, giving hard ores in the eastern end of the range, while toward the west its line of outbreak turns more southerly, passing the head of lake Superior at Duluth, but apparently forming a bed of conglomerate and breccia along the ore belt, noted at various places between Gunflint lake and Pokegama falls.

3. A peculiar siliceous rock, partly jasperoidal, partly of hard hematite, or hard limonite, sometimes conglomeritic and brecciated, cherty, flinty, usually gray, sometimes partly black or purple, and, toward the west, kaolinic, toward the east hold-

ing some magnetite. Altogether this is a non-descript rock, which sometimes is fifty feet in thickness, but so far as developed near the mines is less than twenty. It is a pretty constant rock and when the ore is absent it lies on or varies to the Pewabic quartzyte. This is the horizon of the hard hematite, hard limonite and of some of the non-titanic magnetite. In some way not yet fully determined it is associated with the next. It is not yet certain that all the soft ore is derived from a change of this rock to ore, but it is very certain that in some cases this rock is converted to ore. It overlies, apparently, the chief ore body of the range, or its lower portion is changed to ore.

4. The chief horizon of soft hematite. The greatest thickness this bed has yet been found to exhibit is 105 feet. In the midst of this ore are found sometimes irregular masses of rock like No. 3, as if remnants of that stratum not yet converted to ore, while some strata of soft ore are found also in the midst of No. 3. Not enough working has been done yet to reveal all the relations of the ore to No. 3.

5. Pewabic quartzyte. In the near vicinity of the gabbro foci this is remarkably modified. Originally probably a chemical oceanic precipitate in its upper portion it is consolidated to a vitreous quartzyte, but at more distant points it is composed of distinct rounded grains. The upper portion is in the form of chalcedonic silica (so-called), a phase which extends westward with modifications, so far as observed, at least to town 60-13. On the other hand this quartzyte becomes less siliceous, having a feldspathic element, and even an olivinitic constituent, and sometimes large hornblende crystals embrace the quartz grains in a common matrix. When olivinitic it is also magnetitic and constitutes an important iron ore. In some places farther west, near the Mississippi river, is a quartzyte which is evidently the same, regularly interbedded with magnetite in thin alternations.

6. Conglomerate. This is simply the base of the quartzyte, and takes on the character of the older underlying rock. When it lies on the greenstones its cementing matrix is green, when on the granite it is more siliceous and lighter.

Northward from the strike of these strata extends the Archæan complex, embracing the rocks and ores of the Vermilion range and the foregoing beds lie unconformably on the upturned edges of the older rocks where the two formations come into contact. But, wherever the highland spurs of the older rocks extend

further southward, the primordial strata sweep about their bases, dipping in opposite directions on opposite sides of the spurs. They occupy no constant level, which might be considered an oceanic shore line, but they seem to exist where erosive agents have not been able to remove them. Hence they may have extended formerly much further north. It happens, however, that a range of granitic hills, the Giant's range, occurs but a short distance to the north, and sometimes the strike of the Taconic is coincident for some miles with the southern base of this range. In other places a belt of "greenstone," which, however, is itself rather rough and rises nearly as high as the granite hills, intervenes between the Taconic and the granite.

It is evident that the present surface contour is but a poor guide to the stratigraphist in attempting to determine the relative ages of these terranes, for the surface must have suffered a profound degradation. The gabbro rock, which is by all conceded to be an irruptive rock, shows no sign of ever having outflowed at the surface of the earth. It is not bedded by amygdaloidal partings, nor has it, so far as known, any variable texture due to contacting with other older rocks. Yet it comes into contact with various older terranes, having crowded backward upon them while yet confined within the crust of the earth, without reaching the surface. It has been seen overlying the Pewabic quartzyte, the Keewatin greenstone and the granitic rocks of the Giant's range, but maintaining everywhere a coarse and crystalline texture. It seems as if the irruptive movement must have been very slow, and that it progressed not forcibly, but as rapidly as the heating of the adjacent rocks rendered them more flexible. Subsequent to the molten invasion the surface degradation took place revealing the deep-seated contacts which we see. It has been the writer's opinion that this event of the eruption of the gabbro took place immediately after the deposition of the Pewabic quartzyte, based on the interbedding of that quartzyte with a rock resembling the gabbro, and on the observed immediate overlie of the gabbro on an extensive area of the quartzyte. This observed overlie, however, loses its importance when it is learned that the gabbro also overlies the Keewatin and the crystalline granite of the Giant's range, and the date of the disturbance will have to remain, as heretofore, not definitely established.

In further considering, however, the Mesabi iron ore, certain problematic difficulties appear in the way of accepting any of

the proposed theories for the origin of the ore. These may be enumerated:

1. There is no limestone known in the region which could be considered the parent rock giving rise to this ore by a process of substitution, nor has there been any struck by any of the diamond drills that have recently been driven through the ore horizon.

2. There is no known horizon of spathic iron which can be considered to have been converted to oxide.

3. There is no dissemination of carbonate of lime in the form of calcite, such as to indicate that the ore may have resulted from a substitution of iron for lime. The sparse mingling of minute fragments of calcite crystals, in microscopic sizes, with the silica of the chert, in some of the less ferruginous parts of the formation, is hardly sufficient to account for such a vast deposit of iron ore. It seems like trifling with the problem to appeal to such a cause for the ore.

4. As to concentration by decay of ferruginous schists —the process seems to have been the reverse, viz., from the ore has been diffused iron oxide through non-ferruginous schists, so that for several feet from the ore the surrounding rock is stained a vermilion or brownish red. This has not only affected some of the green schists, but also some of the underlying quartzyte. And again, on the theory of ferruginous concentration from schists, or from any rock, it is necessary to explain the singular fact—singular under that hypothesis—of the occurrence of the ore always at the same stratigraphic horizon in the same formation. Why should not this ore accumulate, at least sporadically, at some lower or slightly higher stratigraphic horizon? Here we find it, for 150 miles, maintaining its position in the series as constantly as any of the beds that are associated with it.

5. The absence of dykes of irruptive rock. These have been supposed to have played an important role in the concentration of the hematites of the Penokee range, on the south side of lake Superior. Yet, on the north side but one such dyke has been discovered, and that is in the eastern extension of the iron range where, notwithstanding a year's costly exploration in the vicinity, no hematite has yet been found in commercial quantities. At the western end of the range, where the recent discoveries have been made, not a single dyke has been discovered. Further, the strata that enclose the ore are not impervious, and could not form troughs

by any combination of dyke and dip, but the underlying rock is a loose white sandstone. It has sometimes become deeply stained by the downward percolation of surface waters carrying the ore mechanically amongst its rounded grains.

6. There is an apparent extensive change in the rock of the country. The details of this change cannot be given here. As one stands at the brink of one of the excavations and sees distinctly a sweep of plainly originally sedimentary layers, across the face of the cut, manifesting all the usual characters of sedimentation, and reflects that the strata which he now beholds consist of bessemer hematite, slightly brecciated, soft, easily mashed, he is driven to one of two conclusions—either, first, that the ore was deposited as a constituent part of a sedimentary series, or second, that it is the result of some grand substitution process by which hematite has been made to take the place of the original sediments. There are besides numerous minor evidences of some transition in the rock from its original composition to hematite, viz.:

(a) Sometimes a gradual encroachment of a hematite coloration from the outer portions of a block, or layer, upon a gray or blue central area.

(b) Sudden cessation of a band of hematitic coloration at a fissure which evidently the waters producing the coloration could not pass, and the passage of the same waters, as shown by the narrow streak of hematite in the fissure, down the fissure away from the band before affected, leaving that portion on the other side of the fissure unstained—while at the same time the sedimentary banding of the whole rock sweeps unimpaired across the whole face, from one side of the fissure to the other.

(c) There are larger areas where, as revealed by some of the shallow shafts on the western end of the Mesabi range, there is an abrupt change, horizontally, from rock to ore, the separating line being distinct for a perpendicular distance of at least two feet. In other places in the same shaft the ore and rock encroach irregularly upon each other. In these cases the ore is soft red hematite. If the process of substitution were now going on it would be reasonable to expect the oxide would be hydrated, especially as such transition is within a few feet of the surface and easily accessible by atmospheric waters.

(d) Not only is the rock changed *in situ*, but as breccias and gravels large deposits are found in which the pebbles, rounded as in a river current, or on an ocean beach, are converted to

hematite. Such pebbles were rounded, while still rock, and were subsequently converted to hematite. This is evinced by the varying texture, and concentric structure which change somewhat regularly from the surface to the center, the outer crust being dense and the central portions being vesicular. Whether such pebbles appertain to the rocky strata, or are of the age of the drift, has not as yet been determined.

Some necessary postulates.

Notwithstanding it seems inadmissible to adopt any theory proposed hitherto for the origin of this ore, and that we are not qualified to propose a new one, there are some important facts which must be taken into account when the true explanation is discovered. These facts, which are based on observations made partly during the present season, may be set down severally as postulates on which some satisfactory theory may possibly be, in part, built at some future time.

1. The ore has a definite position in the stratification.
2. It is underlain by a porous quartzyte.
3. It is overlain by, or results from a change in a peculiar rock to which we have given the name taconyte. [To be described fully at a later date.]
4. The whole ore bed is sometimes a breccia of some sedimentary rock, lying loose, and sometimes compact brecciated or even conglomeritic phases are common. Rarely a pebbly ore is found.
5. It is associated with much kaolinic, but water-stratified rock, and often the white kaolin, though embraced in the ore, is unstained by it.
6. It occurs at the same horizon the whole length of the Mesabi range.
7. When the gabbro of the Mesabi range is adjacent this ore is found to be hard—either hematite or magnetite, but it is never affected by titanic acid—though it is by sulphur under such circumstances.
8. Apparently it runs southward with the dip of the formation, and by boring it is found under a large thickness of black slate about a mile south of the line of strike.
9. The horizon of the ore is the same that has been assigned by the writer to the date of the disturbance of the gabbro flood. But as that assignment is not sufficiently established it cannot be said that the ore has any relation of cause and effect to the gabbro.

Conclusion.

There are but two items in the conclusion to which we are driven:

First. The Mesabi ore is not satisfactorily explained by any theory that has yet been proposed for it, or for its equivalent (Gogebic) ore on the south side of the great lake. There are some facts that favor all of the theories that have been proposed, but they meet with opposing facts of greater import.

Second. There is but one known cause acting with sufficient force and on a geographic area sufficiently wide, to which we can appeal for the geographic and stratigraphic distribution of this ore—and that is *oceanic sedimentation.* That there has been a profound change in the sediments since their origination is quite evident; but whether this change took place, in whole or in part, prior to consolidation or after it, is as yet unknown; and if after consolidation it is equally unknown whether it was accomplished in Taconic or in Recent time. There seems to have been something peculiar either in the nature of the sediments of this horizon or in the influences to which they have been subjected, and this peculiarity is expressed on both sides of the Lake Superior basin.

(Other field notes made in the season of 1892, pertaining to the region of Snowbank lake and thence northeastward to Knife lake, will be reserved for the final report, likewise those of a re-examination of points on Gabimichigama, Flying Cloud and Kekequabic lakes, and of a visit to the Twin peaks.)

REMARKS ON THE SO-CALLED MUSCOVADYTE OR MUSCOVADO ROCK.

In several of the annual reports of the Survey an undefined term has been used to designate a rock of certain macroscopic characters that prevails along the northern limit of the gabbro. The term has been used because of its convenience in the field and because of its expressing at the same time the general outward character of the rocks to which it was applied. There is no doubt, however, that in many cases these rocks have been collected without receiving this designation. It is thought best to make some examination of some of these rocks to determine their petrographic characters and, if possible, their structural relations. In all cases the field relations have to take precedence in discussing their origin and systematic relations. By means of microscopic and chemical examination, however, some intimate mineral associations are determined,

which throw light upon their probable origin. Several of these that have been designated muscovado have been sliced and mounted by Mr. Ogaard and examined microscopically by Dr. Grant, and some chemical analyses have been made by Mr. Meeds.

The term muscovado seems to have been used first in the fifteenth annual report, page 351, and applied to rocks collected in secs. 15 and 16, 63-9W., on the northeastern waters of the Kawishiwi. It is here part of a biotitic, more or less gneissic rock with more or less quartz, which by later study has been separated from the gabbro, although at the time the rocks were collected they were supposed to be a phase of the gabbro.

Dr. Grant has made the following microscopical notes on No. 983.

Description of No. 983. Kawishiwi River.

Macroscopical:—A grayish rock of rather fine grain. The hand specimen is homogeneous throughout and shows no gneissic or other parallel structures. It is compact and not crumbling. Numerous glistening scales of biotite are easily seen, and under the lens the rock appears granular, but the constituent minerals cannot be made out, although one would judge that quartz formed a large part of the rock. Rock appears fresh. Does not effervesce with cold hydrochloric acid.

Microscopical:—The section shows a closely compact, fine grained, granular mixture of quartz, feldspar, biotite, iron ore, and a mineral referred to pyroxene. The grain is so fine that under crossed nicols the different grains are not all distinctly separated, nor do some of them extinguish completely; this, however, is due to the overlapping of the grains; there is no "amorphous" or "chalcedonic" silica present (compare section of jaspilyte in Bul. 6, pl. 8, fig. 1). The rock is thus completely crystalline, and is quite fresh.

The *biotite* is the most noticeable mineral; it occurs in large flakes which often hold many pieces of quartz, some magnetite, and occasionally pyroxene.

The *pyroxene* is in small rounded grains and elongated ones which, however, never show any crystal faces. It has quite a high index of refraction. It contains enclosures of magnetite and numerous transparent areas which seem to be liquid cavaties. A slight cleavage is often developed parallel to the long axes of the grains. The extinc-

tion is almost always parallel to this cleavage and the mineral often is slightly pleochroic; from these two facts it is referred to the group of orthorhombic pyroxenes—probably it is enstatite or bronzite. On account of the smallness of the grain and the difficulty of obtaining a good interference figure with the instrument in use, the optical properties were not further studied. This mineral is greenish in color. In the pleochroic individuals the ray vibrating parallel to the cleavage is colorless or greenish and the other of a very light pinkish or reddish shade. This corresponds to the pleochroism of orthorhombic pyroxenes. The *iron ore* is undoubtedly magnetite; it is in small grains with more or less distinct faces, but with the angles rounded.

The pyroxene and iron ore are probably older than the mass of the rock which is composed of quartz and feldspar, and the biotite encloses all.

The *feldspar* is abundant; it frequently shows polysynthetic twinning, and is thus plagioclase; but the kind of plagioclase is uncertain. There is also considerable feldspar which is not twinned and which may be orthoclase, or untwinned plagioclase.

The *quartz* is in fine grains, even finer than most of the feldspar. There are many grains, which show no cleavage, or twinning, whose nature it is not easy to determine. Many of such grains, supposed to be quartz, give a biaxial interference figure; and others give no distinct figure. I examined about 20 sections which I thought might be basal sections of quartz; only one out of these 20 gave a distinct uniaxial interference figure; this was tested and found to be +. Four or five gave biaxial figures; and the others gave no definite figures. The feldspar is unaltered, and so is hard to distinguish from quartz, when twinning, cleavage or interference figures are not to be seen. It is my opinion that there is much less quartz in the rock than I had supposed. Thus, so far, I am sure of but one grain; there are, however, undoubtedly more, but I should guess that quartz makes up less than 1-10 of the rock, and I feel certain that it does not make up 1-5 of the rock.

The magnetite of Nos. 982 and 983 was tested for titanium, but none was found.

The rock now shows nothing that can be taken as proof of an original clastic nature. It is lithologically a fine grained quartz biotite noryte. It may be a recrystallized sediment or an original eruptive.

These rocks have been identified under this name at several places, viz., on Disappointment lake by H. V. Winchell*, who considered this muscovado to be a changed mica schist, and his general description makes it evident that at that place the muscovado has no connection with the gabbro. It was also observed on Illusion lake by A. Winchell† and by N. H. Winchell‡.

No. 1039. Island in Illusion lake.

A light gray rock of fine grain holding numerous and distinct flakes of biotite. The section is made of fine grained granular quartz with some orthoclase. In this are scattered numerous biotite scales.

At this place the rock was likewise considered to be a part of the gabbro, but it is evident that it is a part of the older (Archean) rocks that have been affected by the gabbro contact, at least the rocks of the islands of the lake; the south shore may contain a true gabbro or eruptive muscovado. It is again known on the river flowing northward into Kekequabic lake, S.W.¼ N.E.¼ sec. 11, 64-7 W., where it is reported to contain grains of reddish feldspar and some quartz, and is probably a part of the older rocks. It is reported abundant about the eastern and northeastern shores of Gabimichigama lake. Dr. A. Winchell described and illustrated an observation on an island in this lake, where he found coarse crystalline gabbro lying upon and embracing angular fragments of muscovado, the interstices being filled with gabbro. His figure (56) is here reproduced. Further examination of

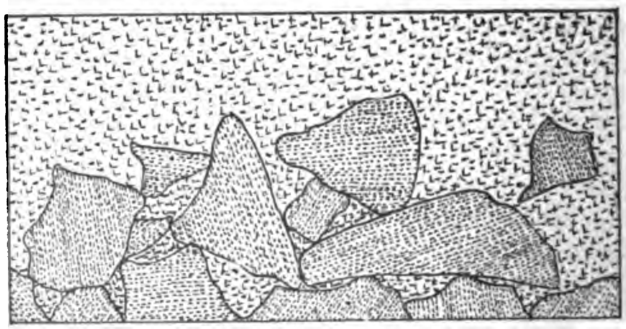


Fig. 56. Gabbro on "muscovado" fragments, Hall 841, Gabimichigama Lake.

*17th Ann. Rept., pp. 116, 117, 130 and 131.
†15th Ann. Rept., p. 183.
‡Ibid., p. 359.

this lake has revealed the fact that the rock here called muscovado is a part of the Archean affected by contact with the gabbro. Numerous specimens have been collected at points further northeast, where this underlying rock is exposed in many islands and low shores, and where its fragmental and stratified characters are more evident. Rock 1088 was collected on the little island at the entrance to the bay which forms the northeasterly end of Gabimichigama lake. It is found in other islands farther north and along the shores. On the east side of the bay it was found to be overlain by characteristic coarse gabbro. Of this rock Dr. Grant has made an examination as follows:

Description of No. 1088 (15th Ann. Rept., p. 379).

Macroscopical:—This rock apparemtly would be included under "muscovado." It is a fine grained, seemingly granular, rock of a grayish or brownish-gray color. It contains a few small white spots which look like feldspar; shows no parallel structures in hand specimen. Appears pretty fresh. Does not effervesce in cold HCl. It is too fine grained for study with the lens.

Microscopical:—A fine grained aggregate of quartz and biotite. The latter seems to make up about ⅓ of the rock; biotite is in small scales arranged in no order. The quartz is in small sub-angular, angular and irregularly outlined grains imbedded in a very fine grained matrix which is also apparently quartz. I recognized no other minerals. The rock is undoubtedly part of the clastics of the region.

Description of No. 1089 (15th Ann. Rept., p. 379).

Said to be "the same as No. 1088, but shows an intenser action of the gabbro;" from the north side of Muscovado point.

Macroscopical:—A fine grained gray rock, much like No. 1088 but not showing the brownish color.

Microscopical:—Rocks composed of biotite, quartz and amphibole(?). Quartz and biotite about as in No. 1088; some of the biotite has faded and become almost colorless. A few small grains of magnetite are present. All through the rock is an indistinct light greenish to light yellowish mineral, sometimes massed together in aggregates of fine grains and fibers and sometimes in minute particles all through the rock. In a few veins are also accumulations of this mineral. While not

very clearly defined, still this mineral seems to be an amphibole, perhaps actinolite.

This rock also is undoubtedly part of the clastics.

Rocks from the south side of Muscovado point were also examined, viz., 1090, 1091 and 1092, and 1350 from the north side.

Nos. 1090 and 1091 (15th Ann. Rept., pp. 379-380).

1091 and one slide of 1090 are essentially similar to No. 1088, with only slight differences.

Another slide of 1090 is somewhat coarser grained and has a confused altered appearance. It is composed of feldspar, both polysynthetically twinned and not, quartz, biotite, magnetite, hornblende and what I take to be an almost colorless pyroxene. The last appears in places to be altering to hornblende. Some of the feldspar has become cloudy. No evidence of a clastic structure remains in the rock.

No. 1092 (15th Ann. Rept., p. 380).

This is essentially the same as the last described slide of No. 1090, except that considerably more hornblende is present and the pyroxene is in larger and better defined pieces.

No. 1350 (16th Ann. Rept., p. 89).

Is finer grained than the last, but is very similar to it in composition.

These muscovado samples about Gabimichigama lake are from the general formation, which can be traced continuously in one direction into the great Ogishke conglomerate, *i. e.*, toward the northwest, and eastwardly into the so-called greenstone at Flying Cloud lake and Akeley lake, and therefore have no connection with the gabbro proper.

On an excursion, which was made from Gabimichigama lake eastward to Flying Cloud lake, this relationship to the greenstone was plainly brought out. Samples also were collected, viz., 1780 and 1781, the former from the N.E. ¼ N.E. ¼ sec. 34, 65-5 W., and the latter from a point a little farther east, both on the north side of the creek, which here, for some distance, marks the boundary line between the greenstone and the Pewabic quartzyte. The quartzyte is seen to dip, at an angle of about 45°, southwardly, rising in a continuous strike about 40 or 50 feet above the creek on its south side; while on the north side the greenstone occurs in scattered low knobs, but rising within a

short distance to a hight of perhaps 200 feet above the creek, having its characteristic topography. These features extend eastward to Chub (Akeley) lake and further, where they have been also described.*

No. 1780. This is a part of the underlying greenstone form ation.

The section shows a confused, more or less granular aggregate of plagioclase, hornblende, biotite, pyroxene (diallage?) and magnetite. The pyroxene seems to be altering to hornblende, in fact all of the hornblende, which is in large amount, may perhaps come from this source.

No. 1781. Along stream east of last; also underlving the quartzyte, in fact immediately below the quartzyte. The section shows a rock quite similar to No. 1780, but containing more biotite and some hornblende which is probably secondary. A granulitic gabbro lithologically.

It will be noticed that the characters of the rocks 1780 and 1781 show a much more basic nature (also indicated in the field) than those that are above described from Gabimichigama lake It will also be noticed that the strike of this older formation at Gabimichigama lake, as well as at Illusion lake and on the northeastern waters of the Kawishiwi, is about north and south; this being an irregularity in the usual northeastward trend of the Archean in northeastern Minnesota. Thus it appears that, in passing eastward from Gabimichigama lake, we first pass across the strike and soon enter upon a greenstone which resembles that of the Twin peaks. It is not necessary at this place to consider the question whether this greenstone and the so-called diabasic and gneissic rock, seen below the gabbro, are of the same formation; it is sufficient to say that all the evidence that the Survey has at hand tends toward that conclusion.

All of the foregoing examples of so called muscovado are from the underlying Archean rocks, and, therefore, do not illustrate the original idea of muscovado, that it was a form of the gabbro; while at the same time when the specimens were collected, they were supposed in some cases to be from the gabbro itself modified by contact with the sedimentaries. We have now to mention other forms of so-called muscovado, which lie in a belt of country further south, even south of large areas of characteristic coarse gabbro.

*16th Ann. Rept., pp. 82-86.

There is a lake in sec. 36, 65-5 W., named Muscovado lake from the prevalence of this rock, and about its western shores and extending southwestwardly into sec. 3, 64-5 W. is an extensive hill range composed of muscovado rock. This hill range lies to the south of an area of fresh crystalline gabbro, which again also lies to the south of the strike of the Pewabic quartzyte, above mentioned. The quartzyte and gabbro distinctly dip to the south, and, if there be no fault in the region, this muscovado must lie above a large amount of gabbro. It has been sampled and sliced, and the following examination was made by Dr. Grant:

No. 1784. Muscovado, north end of Muscovado lake.

A fine grained *noryte.* This specimen (macroscopically) appears to me to be "*typical muscovado.*"

The section is especially beautiful. A granular aggregate of plagioclase, hypersthene, which is beautifully pleochroic, and titanic magnetite. This rock, except in the large amount of hypersthene, is the same as those from Bashitanaqueb lake, which see.

Mr. Meeds "found a very strong test for titanium" in this. He powdered the rock and by the magnet got considerable of the magnetite, which he tested with the above result.

Other samples have been collected from the shores of Bashitanaqueb lake, the north side of which lies largely in this rock. These have also been examined and found to have the following microscopic characters:

Specimens from Bashitanaqueb lake.

On the north shore of this lake are fine exposures of this rock. A number of specimens have been collected here. Here are probably the best exposures of this rock south of the north limit of the gabbro.

The specimens taken here and sectioned are 1785, 857G, 857 AG and 857BG.

These rocks are rather fine grained granular aggregates of plagioclase, pyroxene (mostly diallage), magnetite, and sometimes a little olivine and biotite. They are *gabbros* petrographically. Some pleochroic pyroxene (hypersthene) is sometimes present, and pinkish diallage is frequent.

No quartz was detected. Secondary hornblende is sometimes seen.

Analysis of No. 857G. Mr. Meeds reported the following chemical composition of one of the above samples, 857G.

$Si\,O_2$	49.07
Al_2O_3	17.21
Fe_2O_3	.46
$Fe\,O$	12.18
$Ca\,O$	9.66
$Mg\,O$	3.60
H_2O	1.55
Na_2O	2.96
K_2O	trace
CO_2	2.70
$Mn\,O$	trace
Total	99.89

The CO_2 above is probably due to decomposition products, as the rock is not entirely fresh.

In addition to the differences here indicated by chemcial analysis and by the microscope between this southern muscovado and that before described, belonging to the Archean, there are also structural differences which are very noticeable in the field, viz.; this southern muscovado never shows the knotted and seamed condition and the quartzose veinings and the gneissic structure and vertical attitudes seen in the northern muscovado. Taken altogether it is a much more homogeneous and massive rock, its only variation consisting in a bedding or sheeted lamination, dipping toward the south, conformable with the general gabbro structure, such sheets sometimes being not more than an inch thick. The most remarkable exhibition of this sheeting, which has been seen, is at the east end of Muscovado lake on the north shore.

Similar muscovado has been collected by Mr. H. V. Winchell near the west quarter post of sec. 14, 63–9 W.;* and of this rock Dr. Grant has given the following microscopical description.

No. 505H. *Macroscopical:*—A rather fine grained rock of a gray to brownish gray color. Not gneissic. Composed of grains of a glassy mineral and smaller ones which are yellowish to black in color.

Microscopical:—A granular aggregate of feldspar, pyroxene, olivine, magnetite and a little biotite. The feldspar is largely, perhaps entirely, plagioclase. Some grains do not show twinning striæ, and in some the cleavage is not well marked. Such grains might be quartz; however, a dozen such grains which, if quartz, would be approximately basal sections, were examined for interference figures and every one showed a distinct biaxial

*17th Ann. Rept., p. 120.

figure. I think there is no quartz in the section. The pyroxene is distinctly pleochroic, and is probably hypersthene. The minerals of this rock, except the olivine, are unaltered and fresh.

The rock is lithologically an *olivine noryte* of rather fine grain. There seems no reason for considering this rock a metamorphosed sediment; it shows all the characters of an eruptive of the gabbro family.

The south east shore of Illusion lake also contains this form of muscovadyte, shown by

No. 1037. Illusion lake.

This is a fine grained brownish gray rock. In section it is seen to be composed of a fine granular aggregate of feldspar (largely, if not entirely, plagioclase), pyroxene and magnetite. The pyroxene is in large amount and is both diallage and hypersthene. This rock seems to belong to the gabbro phase of the muscovado.

Conclusion.

It would appear from the foregoing that the term muscovado rock (or muscovadyte) has been applied in the field to rocks of different stratigraphic position and origin. This has already been asserted by Mr. H. V. Winchell in the seventeenth annual report, pages 130-131. It is also apparent that one of these is producod by the action of the gabbro upon the sedimentaries. It appears also probable that the southern belt of muscovado is a phase of the gabbro proper and that, if to either the name should be continued, it should be applied to this southern belt.

There remains, however, this possibility, if not probability, that this southern muscovado represents the profound action of the true gabbro upon a basic Archean greenstone, which has been brought to the surface in the midst of the gabbro area by a later fault. We have learned from numerous observations that all the rocks in this region have in some places been extensively faulted. It will be well, therefore, still, before adopting this duplicate theory of the origin of the so-called muscovado, to examine further critical specimens collected at points where it can be shown that the true gabbro was superposed upon a basic greenstone of Archean age.

VI.

ADDITIONAL ROCK SAMPLES COLLECTED IN 1892.

TO ILLUSTRATE THE REPORT OF N. H. WINCHELL.

1627. Hard hematite, the ore of the Mesabi Iron Co.'s land, sec. 27, T. 60-13, one mile south of the granite.

1628. No. 2 of the drill at Wicks', black and gray fine banded rock, with magnetite.

1629. No. 3 of the drill at Wicks', "black slates."

1630. No. 4 of the drill at Wicks', gray quartzyte, sometimes porous, also sometimes non-homogeneous with angular and rounded masses.

1630 A. Siliceous balls or concretions from 1630.

1631. No. 5 of the drill, ore.

1632. No. 6 of the drill, fine-grained pinkish quartzyte.

1633. No. 7 of the drill, crystalline quartzyte; it contains fragmental quartz cemented in a matrix of quartz.

1634. No. 8 of the drill, "greenstone" materials embracing many pebbles and grains of quartz.

1635. The lower portion of the last.

1636. No. 10 of the drill, granite.

1637. Sample of rock like 1634, but taken from the NE. ¼ SW. ¼ sec. 22, T. 60-13; mainly fragmental material in which are conspicuous fragments of lavender quartz, supposed to be from the granite.

1638. An extreme phase of 1637, mostly quartz; SE. ¼ NW. ¼ sec. 28, T. 60-13.

1639. Greenish rock, supposed to be the fragmental substance more scantily disseminated through 1638. Same locality as 1638.

1640. Pinkish fine quartzyte. NW. ¼ NE. ¼ sec. 32, T. 60-13.

1641. Magnetite from NW. ¼ NE. ¼ sec. 32, T. 60-13; natural loadstone, only found in small quantity; blends off into the rock of the iron belt (1631 of the drill record).

1642. Represents the average characters of the rock at the silver pit opened by Chester; it is Keewatin but quite (finely) siliceous; quartz veins are numerous; compare 442, also Bulletin No. 6, page 203 and foot-note.

1643. Republic Mountain, Mich. Quartzyte or greissen, supposed by Wadsworth to be of eruptive origin.

1644. Greenstone from the north side of the Republic hill, approaching hornblende schist.

1645. Hematite from the non-conformable conglomerate or upper iron horizon at the Goodrich mine, Mich.

1646. Potsdam quartzyte, Clarkson's quarry, Potsdam, N. Y.

1647. Light pink gneiss from the dam in the Racket river at Potsdam.

1648. Darker gneiss from the same place.

1649. Still darker gneiss, same place. These have the appearance of possible derivation from the Potsdam quartzyte.

1650. White marble, Crary's mill, 7 miles westward from Potsdam.

1651. Gray conglomerate marble, Crary's mill.

1652. Specular hematite from Capt. Wood's mine, 5 miles south from Crary's mill.

1653. Hematite ore from a shaft 4 miles E. S. E. of Potsdam.

1654. Conglomerate in which this ore occurs.

1655. Dark limestone samples, Norwood, N. Y.

1656. Sandstone from Paddock's quarry, 3¼ miles east of Malone, N. Y.

1657. Gabbro from the Adirondacks, as worked for monuments at Keeseville, N. Y.; location unknown.

1658. Fine granular gabbro, same place.

1659. White quartzyte, Keeseville, N. Y.; near the water; dip 8° to 10° N. N. E.

1660. Emery, so-called; seen on the beaches of lake Champlain and at Keeseville on the shores of the Au Sable river; quite abundant. It is gathered and shipped in barrels as emery for emery paper.

1661. The hard quartzyte forming the platform, right bank of the river, Au Sable canyon, below the stairway.

1662. Marble, grayish to white, Gouverneur, N. Y.

1663. Banded quartz rock, near Richland, N. Y.

1664. Ferruginous sandstone, 3¼ miles N. of Richland, N. Y.

1665. Yellow sandstone, same place.

1666. Marble, same place.

1667. Breccia, same place.

1667 A. Impure quartzyte, same place.

1668. Hematite, same place.

1669. Gneiss, DeKalb, N. Y.

1670. One of the smaller segregations of quartz dioryte from the slates at Little Falls, Morrison Co., Minn.

1671. Fragment of the hornblendic layer which encloses the segregation, showing a portion also of the fine softer interior; this interior portion weathers out entirely when they are broken.

1672. Another segregation, hard to the center; also showing garnets in the slate attached; Little Falls.

1673. Garnetiferous slate, Little Falls.

1674. Red, fine-grained granite, sec. 18, T. 41-30, Morrison Co.

1675. Darker, highly micaceous, from the same place.

1676. The same, showing contact with coarser granite.

1677. Keewatin greenstone, from Randall, Morrison Co.

1678. Dioryte, quarried at Little Falls on the west side of the river.

1679. The same, with coarser hornblende crystals.

1680. Still coarser, more gabbroloid in general appearance.

1681. Fine limestone, has a pinkish color, dense in grain; in outcrop on west bank of the Mississippi just below the mouth of Swan river.

1682. Massive mica schist, west side of the Mississippi river near the center of SE. ¼ NW. ¼, sec. 30, 128-29, Morrison Co.

1683. Hardened segregation from 1682, similar to those seen at Little Falls.

1684. Gabbro, Philbrook, near the mouth of the Fish Trap creek, northwestern corner of Morrison Co.

1685. A darker, more magnetited condition of 1684.

1685 A. Subsequently obtained at the same place and sent by Mr. Robert Brown.

1686. White forms of this gabbro (labradoritic?), somewhat quarried.

1687. A sheared schistose condition of this gabbro having a vertical structure; Philbrook.

1688. Three samples of taconyte showing various conditions of change toward hematite, Hale mine, near Merritt.

1689. Conglomerate from the Cincinnati property, but not showing any of the flint pebbles.

1690. Disintegrated quartzyte from the bottom of shaft No. 2 at the Cincinnati mine.

1691. Form showing the penetration of iron into this quartzyte, hardened and reddened, Cincinnati mine.

1692. Taconyte from a shaft on the Cincinnati mine.

1693. Ditto, from the Duluth Ore Co. (Berringer).

1694. Manganese from shaft 23, Biwabik mine, 94 feet down.

1695. Hard blue ore with some soft ore, shaft 25, Biwabik mine.

1696. Pinkish fine quartzyte from the pit in SE. ¼ NE ¼ sec. 4, 58-16, Chicago property; resembles the fine pinkish quartzyte from Wicks'.

1697. Black slates from the well sunk for water at the McKinley camp.

1698. A clayey ball changed to hematitic rock, from the southern pits at McKinley's; probably from the black slate horizon.

1699. Iron gravel, Lone Jack mine, near Virginia.

1700. Mixed kaolin and spongy ochre and hematite, Mesabi Mountain mine, near Virginia.

1701. Banded kaolin, same place.

1702. Flinty, fine grained rock associated with the kaolin, varying from white to pinkish; apparently a part of the kaolin stratum; same place.

1703. Lump of taconyte showing various changes of some of its ingredients to hematite and gœthite; Security mine, near Virginia.

1704. Kaolin, Mesabi Mountain.

1704 A. Silica balls from 1704.

1705. Hard, conglomeratic, jaspery ore, Virginia mine. Over this bed is a stratum, thickness unknown, which has received the local designation "stove-plate rock," because it is in thin, heavy, firm sheets, regular and sonorous, sometimes becoming a lean ore. This conglomerate and the "stove-plate rock" apparently belong below the main ore horizon.

1706. Hard hematite, with kaolin in specks disseminated throughout; also with other rounded pebbly parts.

1707. Crucial specimen from the crucial pit on the Virginia; taken from the point of transition between the rock and ore, one specimen showing both. See fig. 16.

1708. A dark, massive portion of the black slates, near the Partridge river, a little west of Allen Junction; very silicious, though not properly a quartzyte.

1709. Magnetite ore, non-titanic, and associated with vitreous quartz; SW. ¼ NW. ¼ sec. 4, T. 62-11. Probably from the Vermilion; same as that at the rapids at north end of White Iron lake.

1710. Rock associated with magnetic ore at Spellman's, north side of Birch lake, about 200 feet from the granite; sec. 23, T. 61-12.

1711. Magnetic ore taken from this pit.

1712. Hornblende rock from the same pit; thought to be the footwall.

1713. Sample of the hanging wall of the pit, granitic in aspect, though allied to the gabbro; siliceous; from Mr. Honnald, superintendent.

1714. So-called black slate, presented by Mr. Honnald; in his opinion this overlies all the ore and the rock concerned.

1715. Quartzose gneissic rock, or quartzyte. It is from the small island in the Kawishiwi river, NW. ¼ SE. ¼ sec. 19, T. 63-9. (See No. 981, 16th report.)

1716. Similar to 1715; from the island next south of the last island. This does not manifest any sedimentary characters but is variable in its fineness of grain as well as in its manner of decay. This island is within 60 feet of the south shore.

1717. Fine grained olivine gabbro, or coarse grained muscovadyte, from the south shore. These beds stand vertical in the same manner as on the islands.

1718. Red granite, near the center of sec. 2, T. 63-9, Snowbank lake.

1719. Darker granite at the point near the center of sec. 36, T. 64-9, Snowbank lake.

1720. Greenstone, sec. 34, T. 64-9, west shore of Snowbank lake.

1721. A little further west, and hence near the granite, the greenstone is granitic.

1722. Boot island; this island is composed essentially of red granite. This sample, however, represents the rock at our camp, and also shows a common coarse crystallization of orthoclase occurring in old joints or veins. The rock now disintegrates by opening first along these seams, leaving a layer of coarse orthoclase crystals on each part. This island is in the central part of Snowbank lake.

1723. The rock 1721 develops further east into bold exposures, forming hills 125 feet above the lake, becoming a characteristic coarse conglomerate, hard, semi-granitized, generally green, but weathering with a red tint. This No. (1723) is from a dyke of very siliceous rock, appearing very much like the mass of the formation, cutting over the hill in the NE. ¼ sec. 34, T. 63-9; it is not wholly crystalline, but has some needles, apparently of feldspar; it is 6 in. to 36 in. in width, and weathers light red; it contains no boulder forms, winds about like a dyke and is porphyritic with a feldspar.

1724. A gray, fine grained, crystalline rock; shore of Snowbank lake, NW. ¼ sec. 35, T. 64-9. It appears some like the Ogishke conglomerate, but will have to be classed with the granite. There are areas here that show really granitic structure with abundant orthoclase crystals.

1725. The country rock, SW. ¼ sec. 26, T. 64-9, a short distance east of the last.

1726. Eruptive granite or syenite, in irregular patches, somewhat dyke-like, appearing in 1725, though these two rocks apparently grade into each other. Along this shore is one of the most striking instances of the conversion of a conglomerate into a crystalline rock.

1727. A granitic dyke cuts a micaceous condition of this conglomerate; contact runs about east and west; SW. ¼ sec. 26, T. 64-9.

1728. A micaceous condition of this conglomerate, same place as the last. The dip here appears distinct on the tops of the knobs; about 75°

E. SE., and the strike is 15° E. of N. The dip is such as to throw it under the granite.

1729. Porphyry, on the north side of the same point, in a narrow, westward running bay; this must underlie 1728. This bay is not shown on the township plat.

1730. Porphyry like the last, but irregularly associated with and blending into

1731. A part of the conglomerate. These are both intimately associated with characters pertaining to the Keewatin greenstone rock, of which they seem simply to be advanced conditions toward crystallization.

1732. Mica schist. The conglomerate graduates into this; it is cut by many dykes of red granite. SW. ¼ sec. 24, T. 64-9.

1733. Represents this conglomeratic mica schist in sec. 24, T. 64-9.

1734. Seems to be a portion of 1733, but is a dark gray, fine grained rock, sparingly interspersed with some crystalline red grains; secs. 29 and 30, T. 64-8.

1735. Dark syenitic rock, which takes the place of the granite in forming dykes in 1734; this continues further east, forming the coast.

1736. Dark greenstone, crystalline, SW. ¼ sec. 20, T. 64-8, cut by

1737. Red granite.

1738. Graywacke-greenstone, outlet to Snowbank lake.

1739. Coarse hornblende granite, east side of sec. 31, T. 64-8, Snowbank lake, presenting the so-called "bedded" structure of much of that about Bassimenan lake.

1740. Dike cutting granite in sec. 1, T. 63-9.

1741. Red granite, appearing suddenly in graywacke, on the west shore of Boot lake; NW. ¼ Sec. 21, T. 64-8. It is transitory; graywacke prevails all about.

At the great Knife Lake headland, near the portage to Doughnut lake, the following specimens were collected:

1742. Southwest corner of the headland at the water level.

1743. The same, having a flint film.

1744. The same, having different grain.

1745. A layer 1 foot thick running straight in the rock of the hill for at least 25 feet, when it becomes hidden under the water at one end, and under the soil at the other.

1746. A conglomeritic portion of the rock of the hill, with many pyrite cubes. The rounded boulder forms that are dislodged and roll out are from 3 to 8 inches in diameter, all charged with pyrite, same as the rock itself. The pyritiferous character gradually fades out upward and is entirely wanting at 45 feet above the lake. This is on the north side of the promontory.

The following specimens were collected in making a trip over the headland from north to south:

1747. Twenty-five feet above the lake.

1748. Fifty feet above the lake.

1749. From the northern crest of the hill.

1750. Top of the headland near the center.

1751. From the southern crest of the hill.

Anyone examining these would at once pronounce them all the same rock, excepting 1745 and 1746. They appear very much like gabbro, and the general physical aspect of the hill and the jointage of the rock increase the resemblances, but they are probably a condition of the Ogishke conglomerate. The headland may rise 250 feet above the lake.

1752. Sample of a dike cutting grit and argillaceous schist; SW. ¼ NE. ¼ sec. 32, T. 65-6. Dike runs approximately north and south.

1753. Grit, rings like cast iron, cut by the above dike; rather coarse, but some is coarser and some is finer. Pieces of slate are embraced in it.

1754. A fragmental, gritty rock, very hard and gray, outwardly resembling gabbro; the matrix is flinty, but not flint. From a little island in a lake in SW. ¼ sec. 33, T. 65-6. The sample is from a thin bed (6 inches) embraced in the rock of the island. This wedges out as if squeezed into a space of that shape while the whole was semi-plastic. Resembles the rock of the Knife Lake headland.

1755. On the same island the rock 1754 becomes finer, still gray, felsitic, with quartz grains disseminated, exactly like the rock of the pebbles of the Stuntz conglomerate. It is however a portion of the Ogishke conglomerate. Sample shows contact between two aspects.

In ascending the westerly of the Twin peaks with Messrs. Grant and Ogaard, the mountain was found to be made up almost entirely of the so-called ambiguous greenstone, nearly all the way showing conglomeritic structure, but in many cases becoming much like a true irruptive greenstone. That it is wholly fragmental, however, at least on its northern slopes, is the plainest of facts.

1756. On leaving the little lake in sec. 33, we first came upon a low ridge of fine grained greenstone, apparently of igneous origin.

1757. Going on we pass innumerable places where the rock contains boulders and fragments of all sizes and is quartziferous. This specimen shows a prevalent phase.

1758. Shows the coarseness and evident igneous characters.

1759. The same.

1760. Fine grained condition of the country rock on the top.

1761. Coarser grained condition of the country rock on the top. These both look much like true diabases, and no boulder forms appear in the rock.

A dike of diabase, 10 feet wide, runs distinctly through this peak, 45° W. of N., and has characteristic contacts on each side, the contact being fine grained and the center coarser.

1762. Central part of this dike.

1763. Near the edge.

1764. Showing contact with the country rock, the black is the diabase and appears like black slate.

1765. Is a piece of the finer hornblende porphyrel, north side of Kekequabic lake.

1766. SW. ¼ NW. ¼ sec. 31. T. 65-6; sample which seems to be a partial porphyry, partial conglomerate and partial granite. Grant's 787. In this conglomerate here are many pebbles, many of red jasper.

1767. Pebbles from a porphyry knob, SW. corner sec. 29, T. 65-6, on Kekequabic lake.

1768. From the same knob at the NE. extension, where the rock is not porphyritic; fine grained, almost felsitic, not evidently fragmental; graduates into the porphyritic portion.

1769. From the N. side of the narrows of Zeta lake; porphyritic conglomerate or porphyrel.

1770. From the south side of the narrows, near the point. Samples from this place suggested to Dr. A. Winchell the term *porphyrel* for this porphyritic conglomerate.

1771. SW. ¼ NE. ¼ sec. 36, T. 65-6, N. shore of Agamok lake. Hardened, semi-crystalline graywacke, from the summit of a hill about 250 ft. above the lake. The dip is NW. 40°.

1772. NW. ¼ SW. ¼ sec. 31, T. 65-5. Graywacke. This holds pebbles and one of what appears like jasper under water. No dip nor strike visible; doubtfully belonging to the graywacke series. There is a dim appearance of strike northeast.

1773. One hundred yards north of the last is another low sloping surface of similar rock, with still no certainty of dip nor age of the rock.

1774. At the extreme head of the bay; similar rock to the last, rising from the water and forming low ridges. On one of these ridges the dip is plain, varying foom vertical to 70° eastward; strike is north and south. While this rock has some argillitic features, such as those of the black slates seen on Knife lake, yet in most cases it resembles a very fine grained muscovadyte.

1775. From the older formation near the gabbro, on the east side of the northeastward bay.

1776. NE. ¼ SE. ¼ sec. 30, T. 65-5; from hill rising about 150 feet; sample of this doubtful muscovadyte.

1777. Several samples collected from Muscovado point, Gabimichigama lake.

1778. Rather fine grained gabbro or muscovadyte, from the top of the cliff facing north at NE. ¼ NE. ¼, sec. 34, T. 65-5, near the junction of the two branches of the creek.

1779. Sample of the quartzyte from the same place, on the north slope of the hill; some of this appears micaceous.

1780. Just across the creek, north from the foregoing, is the extension of the muscovadyte range, seen yesterday on Gabimichigama lake, but here it has a greenish tinge, approaching the greenstone of Bingoshick lake, as well as that of Twin peaks.

1781. Muscovado greenstone, immediately below the quartzyte; NE. ¼ sec. 35, T. 65-5.

1782. Quartzyte from the top of the ridge, same place.

1782 A. Quartzyte near the contact with 1781. The bedding must amount to nearly 100 feet.

1783. Magnetite from the east end of Flying Cloud lake; from a large, nearly vertical cliff at the southeast corner of the lake.

1784. North side of Muscovado lake. This is a remarkable rock, as it resembles muscovado, which we suppose to be the result of a change in sedimentary rocks; it is a remarkable circumstance also that so far south, within the gabbro area, so much of this rock is found. It is heavily jointed, nearly horizontal and slides in sheets into the lake towards the southeast, the sheets being from ½ inch to 6 inches thick. Small nodules weather out on the surfaces and some larger, harder patches also appear, resembling some seen in the changed graywackes on Gabimichigama lake. This rock prevails about the shores of Muscovado lake, on the shores of the north half of Bashitanaqueb lake, and just north of the latter it forms some high hills.

1785. Muscovadyte from the north side of Bashitanaqueb lake. The south shore of this lake is made up of fresh, gray, coarse gabbro.

In October, 1892, some samples were collected at the original working at the Mountain Iron showing the forms of the quartz in this formation, designed for microscopic examination, viz.:

a. Taconyte, siliceous cement (chalcedonic?), embracing iron ore both massive and in rounded pellets. Magnetite?

b. Chalcedonic silica from the same place, showing inclusions of kaolinic (?) stuff, rounded.

c. Greenish, fine Pewabic quartzyte, clearly striped.

d. Same as c, but coarser.

e. "Quartzyte," a sandstone, apparently feldspathic, rusted in blotches.

VII.

Additions to the Library Since the Report for 1891.

The present list consists of the additions made from Dec. 1, 1892, to Dec. 1, 1893.

A

Albany. Geol. Survey of N. Y., Paleontology, vols. v-viii. An. Reps. xli-xliv. Bulls. State Museum, vol. i, Nos. 6-10. Memoirs, vol. i, 1889.

Altenburg. Mitth. Naturf. Gesell. des Ofterlandes, vol. v, 1892. Verzeichnis Naturf. Gesell. des Ofterlandes, 1892.

Augsberg. Bericht. Naturw. Vereins, 1873-1887.

Austin. Geol. Survey of Texas. Report on Brown Coal and Lignite, 1892. Fourth Annual Report in eight parts, 1893.

B

Baltimore. Amer. Chem. Jour., xv, 1-6, 1893.
Johns Hopkins Univ. Circulars, x, 82, 83, 85, 89, 90, 91; xii, 102-107, 1893.

Bamberg. Bericht. Naturf. Gesell., xvi, 1893.

Basel. Verhandl. Naturf. Gesell., x, i, 1892.

Belfast. Rep. and Proc. Belfast Nat. and Hist. and Philosophical Soc., 1891-1892.

Berlin. Verhandl. Gesell. fur Erdkunde, xix, Nos. 6-10; i-xvi, 1874-1889. Zeitschrift, xxvii, Nos. 3-6, 1892; xxviii, Nos. 1-2, 1893. Verhandl., xx, 1-3, 1893. Mitth. der Köng. Akad. der Wissenschaften, 1882, i-viii; 1883, i-x; 1884-85, i-x; 1886, i-x; 1887, i-x; 1888, i-ix; 1889, i-x; 1890, i-x; 1891, i-x; 1892, i-ix; 1893, i-vii.

Berlin. Deutschen Geologischen Gesell. Zeitschrift, vols. xxiv-xlv, 1872-1893.

Berkeley. Bull. Dept. Geol. Univ. of California, vol. i, pp. 1-72, 1893.

Bern. Mitth. Naturf. Gesell., Nos. 792-873, 1873-1875.

Bologna. Memoirs R. Acad. delle Sci. dell Instituto di Bologna, vol. v, pt. 2, 1892.

Bonn. Verhandl. Naturh. Vereines der Rheinlande, etc., vols. i-iv, v (5-10), 1884-1893.

Boston. Proc. Amer. Acad. Sci. and Arts, W. S. vol. xxvii, N. S. vol. xix, 1891-1892.
Proc. Boston Soc. Nat. History, vols. xv-xxv, 1873-1892.

Brunn. Naturf. Vereines Verhandl, vol. xxx, 1891; Meteorologischen Commission, vol. x, 1890.

Budapest. Foldtani Közlöng Ungarischen Geol. Gesell., vol. xxii, Nos. 5-12; vol. xxiii, Nos. 1-8, 1892-1893.

C

Cambridge. Appalachian Mountain Club, Appalachia, vols. i-iv, Nos. 1-4, vol. vi, No. 4, and vol. vii, No. 1, 1876-1884, 1892-1893.
Harvard College, Mus. Comp. Zool., Bull., vol. xxiii, Nos. 4-6, vol. xxiv, Nos. 1-7, vol. xxv, No. 1, vol. xvi (Geol. Ser.), Nos. 11-14, 1892-1893. Annual Report of Curator, 1891-1892. Rep. of Geol. Dept., 1891-1892. Report on Instruction and Equipment of Geol. Dept., 1890.
Peabody Mus. Amer. Arch. and Ethnology, Prof. Putnam's report to the President, 1891.

Chapel Hill. Jour. Elisha Mitchell Scien. Soc., vol. ix, No. 2, 1892.

Chicago. Brickmaker, vol. xiv, Nos. 3-5, 1893.

Chur. Jahr. Naturf. Gesell. Graubündens, vol. xxxvi, 1891-92-93.

Cincinnati. Jour. Cincinnati Soc. Nat. Hist., vols. v-x, Nos. 1-4, 1883-87, vol. xv, Nos. 3-4, 1893.

D

Darmstadt. Notizblatt für Erdkunde, vol. iv, No. 13, 1892.

Davenport. Acad. Nat. Sciences, Proceedings, vols. ii, pts. 1-2, iii, pt. 1, v, pt. 2, 1877-79-85-89.

Denver. Colo. Sci. Soc. Extr. from Proc. "Production of Columbous and Tungstous Oxides in Forming Compounds of Iron and Tin," 1893.

F

Frankfort. Ky. Geol. Survey, Bulletin, vol. i, 1890. Reports of Progress from 1882-1890. Nineteen reports on various geological features of Kentucky.

G

Giessen. Bericht Oberhessischen Gesell. für natur. und Heilkunde, vol. xxix, 1893.

Glasglow. Trans. Geol. Soc. of Glasglow, vol. vii, pt. 1, vol. viii, pt. 1, and vol. ix, pt. 2, 1883-86-93.
Proc. Philosophical Soc. of Glasglow, vol. xxiii, 1891-92. Index i-xx, 1841-89.

Granville. Bull. Denison Scien. Assoc., vol. vii, 1892.

Good Hope. American Antiquarian, vol. xv, Nos. 1-5, 1893.

Göttingen. Nachrichten zu K. Gesell. der Wissen., 1-16, 1892, and 1-10, 1893.

H

Halifax. Proc. and Trans. Nova Scotian Institute Nat. Sciences, series 2, vol. i, pt. 2, 1891 92.

I

Iowa City. Bull. Laboratories of Nat. Hist. of the State Univ., vol. i, No. 1, 1888, vol. ii, No. 3, 1893.

J

Jefferson City. Geol. Survey of Mo. Bulletins, ii-v, 1890-91. Preliminary Report on Coal, 1891. Report on Iron Ores, ii, 1892. Report on Mineral Waters, vii, 1892.

K

Kiel. Nutth. Mineral. Institute der Univ. Kiel, vol. i, Nos. 1-4, 1888-1892.

Kiew. Memoires de Societé des Naturalistes, vol. xii, No. 2, 1892.

Königsberg. Schriften Physik-okonomischen Gesell. vols. xiv-xvi, 1873-1875, vol. xxiii, 1892. Report of Director of the Museum, 1892. Geol. Samm. des Prov. p.-o. Gesell., 1892.

L

Lansing. Report of Mich. Board of Agriculture, vols. xii, xv, xviii, xix, xxii, xxiii, xxiv, xxx, 1873-4, 1876, 1879-80, 1883-1891. First Biennial Report 1881-82.

Leipzig. Bericht über die Verhandl., 1872-1892. Register, 1846-1885. Bericht der Math. phys. Class, vol. i, 1893.

Lille. Annales Soc. Geol. du Nord, vol. xx, 1892.

Liverpool. Proc. Geol. Soc. of Liverpool, vols. i-vi, 1874-1892.

Lund. Ars-skrift der Lunds Universitets. vol. xxviii, 2, 1891, 1892.

Luneberg. Jahres. der Naturw. für das Furstentum, vol. xii, 1890-1892.

M

Madison. Proc. Wis. State Hist. Soc., vols. xxxvi-xl, 1889, 1892. Historical Collections, ii, iii, x-xii, 1855-1856, 1883-1892. Catalogue of Portrait Gallery, 1892.

Marburg. Sitizungsberichte Gesell. zu Beford. Naturw., 1874.1876-88, 1892.

Mecklenberg. Archiv. der Vereins der Freunde der Naturg., 46th Jahr, 1892.

Metz. Jahresb. Vereins für Erdkunde, vol. xiv, 1891-92.

Mexico. Memorias y Revista de Sociedad Cientifica, "Antonio Alzate," vols. vi, 3-12, 1892-93, and vii, 1-2, 1893-94.

Minneapolis. Minn. Geol. and Nat. Hist. Survey, Twentieth Annual Report, 1891, and Bulletin No. 8, 1892. Zoological Series, vol. i, 1892. Botanical Series, vol. i, 1892.

American Geologist, vol. xi, 1-6, 1893, vol. xii, 1-6, 1893.

Milwaukee. Trans. Wis. Acad. Sci., vols. viii, ix (1), 1892-93.

Montreal. Canadian Record of Science, vol. v, Nos. 3, 4, 7, 1892-93.

Moscow. Societé Imp. des Naturalistes de Moscou, Bulletins 2-4, 1892.

Munchen. Geog. Gesell. Jahresbericht, 1890-91. Polytech. Verein. Bayerisches Indus.-Gewerb., vol. xxii, 23-39, 1893.

N

New York. Trans. N. Y. Acad. of Sciences, vol. xi, pp. 49-58, 1891-92, vol. xii, 1892-93. Annals, vol. vii, 1-5, 1893.

Bulletin Amer. Geog. Society, vol. xxiv, 4, 1892, vol. xxv, 1-2, 1893.

Amer. Mus. Nat. History, Annual Report of Trustees, vols. iii-xviii, xxiv, 1872-87, 1892; Bulletin iv, 1892.

O

Ottawa. Can. Geol. Survey, Decades i-iv, 1859-65. Mesozoic Fossils, i, pts. 2-3, 1884. Palaeozoic Fossils, ii-iii, pts. i. Contr. to Micro.-Paleon. Camb. Sil. Rocks, 1883. Fossil Plants, ii, 1882. Rep. of Progress, 1874-84. Annual Rep., N. S., vol. i, 1885. Maps for Rep. of Progress, 1879-84. Contr. to Can. Paleon., vol. i, pt. 4, 1892. Catalogue of Section 1 of the Museum, 1893.

P

Paris. Soc. des Sci. Nat. de l'Ouest. Bulletin, vol. ii, Nos. 3-4, 1892; vol. iii, No. 1, 1893.
Soc. Zool. de France. Bulletin xvii, Nos. 7-8, 1892. Memoires, vol. v, No. 5, 1892.

Philadelphia. Proc. Acad. Nat. Sciences, ser. 3, vol. xxii, pt. 3, 1892, and vol. xxiii, pt. 1, 1893.
American Naturalist, vol. xxvii, Nos. 313-321, 1893.
Trans. Wagner Free Institute of Science, vol. iii, pt. 2, 1892.

R

Rochester. Rochester Acad. of Science, Proceedings, vol. ii, pts. 1-2, 1891-93.

S

Sacramento. Annual Rep. of State Mineralogist of Cal., vol. viii, 1887-88.

San Francisco. Occasional Papers of Cal. Acad. of Sciences, vol. iii, 1893.

San Jose. Anales de Instituto Fisico.-Geog. Nacional, vol. iii, 1890.

Santiago. Actes Societe Scientifique du Chile, vol. ii, pts. 1-3, 1892.

San Salvador. Observaciones Meteor. Astronomico Observationa, March-May, 1892.

Springfield. Geol. Sur. of Ill., Geol. and Paleon., vols. vi-viii, 1875-90; Plates vol. viii, 1890.

St. Louis. Trans. Acad. Sci., vol. vi, Nos. 3-8, 1892-93.
Annual Rep. Mo. Botanical Garden, 1892-93.

Stockholm. Entomologiska Foreningen, Entomologisk Tidskrift, vols. i-vii, 1880-86.
Geologischen Foreningen Forhandlingar, vol. xiv, 1-4, 1892.
Sveriges Geologiska Undersokning. From Geol. Foren. Farhandl., Nos. 139-147, 1890-91.

St. Paul. Minn. Hist. Society Collections, vols. i-iii, v and vii, 1850-80, 1885, 1893. Seventh Biennial Report, 1893.

St. Petersburg. Russisch-kaiserl. Mineral. Gesell. Verhandl., vol. xxix, 1892, and Materialen zur Geol. Russlands, Band xvi, 1893.
Comité Geologique, Memoires, vol. xii, No. 2, 1891 and Supplement to vol. xi, 1891. Bull. vol. xi, Nos. 5-8, 1892.

Stuttgart. Geog. Beschreibung, 1892, and zur Literatur über Rudersdorf und Umgegend, 1892.

T

Topeka. Trans. Kansas Acad. Science, vols. viii-xii, 1881-1889.

Toronto. Report of the Bureau of Mines, vol. 1, 1891.

U

Upsala. Arsskrift Upsala Universitet, 1878-1885.

V

Vienna. K. K. Naturh. Hofmuseum, vols. vii, Nos, 3-4, 1892, vol. viii, 1-2, 1893.
K. K. Zool. Botan. Gesell. Verhandl., xlii, 3-4, 1892-93, xliii, 1-2, 1893.

W

Washington. U. S. Geol. Survey, Annual Rep., vol. xi, Nos. 1-2, 1889-90. Bulletins 82-86, 90-96, 1891-92. Mineral Resources, vol. viii, 1891. Monographs, vols. xvii, xviii, xx, 1892.
U. S. Army, Annual Rep. Chief of Engineers, i-ii, 1892. Atlas of Annual Rep., 1892,
U. S. Dept. Agrl., Bulletin vii, 1893. Report of Forestry Dept., vol. vii, 1892.
U. S. N. M., Bulletins 40, pt. iv, and 44. Circular concerning Hodgkin Prizes Proc., vol. xvi, Nos. 917-922, 924, 925, 927-930, 934-936, 940-943, 946, 947, 949-955, 1893.
Philosophical Soc. of Washington, vol. v, 1881-82.

Wellington. N. Zeal. Colonial Mus. and Geol. Survey, Annual Rep., xxvii, 1891-92. New Zealand Coleoptra, v-vii, 1893.

Z

Zurich. Naturf. Gesell. Viertelj., 1879-89, 1892-93.

INDEX.

D

E

F

G

P

Q

R

S

ERRATUM.

Page 69, 12th line from bottom: For "Nelson's" read "Nelson Park."

THE GEOLOGICAL

AND

NATURAL HISTORY SURVEY

OF MINNESOTA.

The Twenty-second Annual Report, for the Year 1893.

N. H. WINCHELL,

State Geologist.

MINNEAPOLIS:
HARRISON & SMITH, STATE PRINTERS.
1894.

The Survey

THE BOARD OF REGENTS

OF THE

UNIVERSITY OF MINNESOTA.

HON. STEPHEN MAHONEY, Minneapolis........................... 1895
HON. SIDNEY M. OWEN, Minneapolis............................ 1895
HON. JOHN LIND, New Ulm..................................... 1896
HON. JOHN S. PILLSBURY, Minneapolis......................... 1896
HON. OZORA P. STEARNS, Duluth............................... 1897
HON. WILLIAM LIGGETT, Benson................................ 1897
HON. JOEL P. HEATWOLE, Northfield........................... 1897
HON. GREENLEAF CLARK, St. Paul.............................. 1898
HON. CUSHMAN K. DAVIS, St. Paul............................ 1898
HON. KNUTE NELSON, Governor of the State.................. *Ex-officio*
HON. W. W. PENDERGAST, Supt. of Public Instruction...... *Ex-officio*
DR. CYRUS NORTHROP, President of the University.......... *Ex-officio*

OFFICERS OF THE BOARD.

HON. JOHN S. PILLSBURY.................................. *President*
HON. D. L. KIEHLE............................... *Recording Secretary*
PRESIDENT CYRUS NORTHROP................... *Corresponding Secretary*
JOSEPH E. WARE.. *Treasurer*

CONTENTS.

ILLUSTRATIONS.

ADDRESS.

MINNEAPOLIS, MINN., Aug. 1, 1894.

To the President of the Board of Regents:

DEAR SIR—I have the honor to offer herewith the twenty-second annual report of the Geological and Natural History Survey of Minnesota. It embraces preliminary field reports on a large amount of work, contributed by the various assistants who were engaged on the survey during the season of 1893. It also contains lists of additions to the library and to the museum.

Respectfully submitted,

N. H. WINCHELL,

State Geologist and Curator of the General Museum.

GEOLOGICAL CORPS.

N. H. WINCHELL........................STATE GEOLOGIST
WARREN UPHAM....................ASSISTANT GEOLOGIST
U. S. GRANT........................ASSISTANT GEOLOGIST
L. A. OGAARD..............SURVEYOR AND DRAUGHTSMAN

SPECIAL ASSISTANTS IN 1893.

Paleontology.

E. O. ULRICH, J. M. CLARKE,
W. H. SCOFIELD.

Field geology and topography, in charge of parties.

J. E. TODD, G. E. CULVER,
J. E. SPURR, A. H. ELFTMAN,
A. D. MEEDS, H. B. AYRES,
C. P. BERKEY.

General assistants.

A. N. WINCHELL, E. R. BARTON,
H. B. HOVLAND, H. C. CAREL,
H. E. WHITE, R. P. JOHNSON,
R. M. WHEELER.

I.

SUMMARY STATEMENT.

An effort was made in 1893 to finish that amount of field-work necessary to warrant the preparation of the final report and maps of that portion of the state remaining unpublished. Although there are still many unknown elements in the geology of the northern part of the state, and some considerable tracts, remote from routes of travel, some of which have not been "subdivided" by the township survey of the United States government, which the parties of the geological survey have not been able to visit and map, yet it is thought best to close up the active work in the field and to enter upon the preparation of the last volume of the final report. It was with an earnest desire to round out the present survey with what might be called a final report, showing its completed results in systematic relations, within the reasonable term of a single administration, that the writer, four years ago, volunteered to pledge the completion of the field-work for the sum of twenty-five thousand dollars. This was stated to the appropriation committees of the Legislature of 1891. Fifteen thousand dollars were appropriated by that Legislature. The last Legislature (1893) appropriated ten thousand dollars under similar representations. Although the full sum of twenty-five thousand dollars has not yet been expended on the field-work, yet so much has been done that nearly all the remaining plates, which will represent the geology in the final report, can be drawn. There will be need yet of special examination in some difficult and some important areas, where the opportunities of the past have not been favorable to entirely and satisfactorily understand the geological structure. Practically, however, the campaign of 1893 may be said to have finished the field-work. The rest of the time to be devoted to this work by the writer will be given, as now contemplated, to the preparation of the last final volume, with the necessary accompanying maps.

During the last season parties were in the field under the following assistants:

Prof. J. E. Todd, in the northwestern portion of the state, north and east of Red lake.

Prof. G. E. Culver, in Itasca county.

Mr. Warren Upham, in Aitkin and Cass counties.

Mr. J. E. Spurr, on the Mesabi range and southward in St. Louis county.

Mr. A. D. Meeds, on the Mesabi range and southward in St. Louis county.

Mr. A. H. Elftman, on the Mesabi range and southward in Lake county.

Dr. U. S. Grant, on the Mesabi range and southward in Cook county.

Mr. C. P. Berkey, from Grand Marais northward, in Cook county, and in co-operation with Dr. Grant.

The writer also was in the field in different places, but chiefly in Cook county. Mr. H. B. Ayres began work in Carlton county, but was interrupted by sickness and afterward by other engagements, and accomplished but little. It is planned that he will finish his allotment of work in Carlton county the coming season.

In view of the proposed final mapping of the rest of the state it was deemed highly desirable to obtain such hypsometric data as would warrant the approximate drawing of contour lines in the manner shown on the final plates already published in volumes I and II. Each party was furnished with the necessary instructions and apparatus for platting these lines on the field maps which they carried, while at the same time a continuous hourly reading of a mercurial barometer was recorded at "Mesaba* station," by means of which the simultaneous aneroid readings of the different parties could be corrected and reduced to a uniform basis, and referred to the sea level. In this way a large mass of data was obtained which, when corrected and platted, will result in contour lines, 50 feet separate, over a large area in the northern part of the state. This will give an expression of a preliminary topographical reconnaissance, and will serve as an introduction to the topographical map which it is hoped may yet be constructed. At the same time it is an in-

* There having been great diversity in the spelling of this word, the matter was brought before the *United States Board of Geographical Names*, of which the Superintendent of the Coast and Geodetic Survey is president. On consideration of the various spellings, numbering about half a dozen, it was decided by the Board that the correct orthography is *Mesabi*.

dispensable aid in the understanding of the geological maps and descriptions. Simultaneously with this system of hypsometric readings, a line of levels was run by means of a surveyor's level by Mr. L. A. Ogaard, in company with Mr. Berkey, from Grand Marais across the country to the International boundary, designed to cross what was supposed to be some of the highest land in the state. Many hills, lakes and streams were thus accurately ascertained. This series of levels was widened out to the right or left whenever opportunity occurred so as to include important adjoining points. The highest point found was at the summit of the Misquah hills, 2,230 feet above tide, in the N. E. part of sec. 35, town. 64, range 2 W. The region about is made up of the well-known "red-rock." This range of hills, in its extension some miles further east and west, has nearly as great altitude. The examinations of the season have also demonstrated that the actual water-divide from this place southwestward to Duluth is essentially composed of the same rock, variously mingled with the gabbro of the Mesabi range. The general results of some of these examinations are given in the accompanying reports of the assistants mentioned. More of the details and the final conclusions will be set forth in the final report.

While the accompanying reports give, in the main, the general results of the various field parties, in the words of the assistants themselves, that of Mr. Spurr, who was occupied on the productive portion of the Mesabi range, in the vicinity of Biwabik, McKinley and Virginia, and who has supplemented his field-work by a careful investigation in the laboratory, reaching highly interesting and important results as to the origin of the ores of the range, has been published as a separate document (Bulletin X). The 21st report of the survey has also been issued and distributed. Volume III, of the final report, is still in press. Only a part of the paleontology of the Lower Silurian can be included in the volume. The gasteropods and cephalopods, which the volume had been intended to cover, and for which preliminary contracts had been executed, have to be omitted These chapters, however, will be published at some future date, as now planned, and probably as bulletins of the survey. Of the volume, however, the following chapters were issued since the last report:

Chapter VI. The Lower Silurian Lamellibranchiata of Minnesota. By *E. O. Ulrich.* Pp. 475–628, 8 plates. Published June 16, 1894.

Chapter VII. The Lower Silurian Ostracoda of Minnesota. By *E. O. Ulrich.* Pp. 629-693, 4 plates. Published July 24, 1894.

Other papers by members of the Minnesota geological corps

have been published, as follows, elsewhere. These have a bearing on the geology of the state and of the Northwest.

Volcanic Rocks in the Keewatin of Minnesota. *U. S. Grant.* Science, vol. xxiii, p. 17, Jan. 12, 1894.

Note on the Keweenawan rocks of Grand Portage Island, north coast of Lake Superior. *U. S. Grant.* American Geologist, vol. xiii, pp. 437-439, June. 1894.

Epeirogenic Movements associated with Glaciation. *Warren Upham.* American Journal of Science, III, vol. xlvi, pp. 114–121, Aug., 1893.

Altitude as the Cause of the Glacial Period. *Warren Upham.* Science, Aug. 11, 1893.

Beltrami Island of Lake Agassiz. *Warren Upham.* American Geologist, vol. xi, pp. 423–425, June, 1893.

Englacial Drift. *Warren Upham.* American Geologist, vol. xii, pp. 36–43, July, 1893.

Early Man in Minnesota. *Warren Upham.* Am. Geologist, vol. xiii, pp. 363, 364, May, 1894.

Causes and Conditions of Glaciation. *Warren Upham.* Am. Geologist, vol. xiv, pp. 12-20, July, 1894.

The Niagara Gorge as a Measure of the Postglacial period. *Warren Upham.* Am. Geologist, vol. xiv, pp. 62-65, July, 1894.

The Madison Type of Drumlins. *Warren Upham.* Am. Geologist, vol. xiv, pp. 69-83, with pl. iii, Aug., 1894.

Evidences of the Derivation of the Kames, Eskers, and Moraines of the North American Ice-sheet chiefly from its Englacial Drift. *Warren Upham.* Bulletin of the Geological Society of America, vol. v, pp. 71–86, Jan., 1894.

The Succession of Pleistocene Formations in the Mississippi and Nelson river basins. *Warren Upham.* Bulletin of the Geol. Soc. of America, vol. v, pp. 87–100, Jan., 1894.

How Old is the Earth? *Warren Upham.* Popular Science Monthly, vol. xliv, pp. 153–163, Dec., 1893.

Increase Allen Lapham. *N. H. Winchell.* American Geologist, vol. xiii, pp. 1–38, Jan., 1894.

Pebbles of Clay in Stratified Gravel and Sand. *N. H. Winchell.* Glacialists' Magazine, vol. i, pp. 171-174, March, 1894.

Note on Cretaceous in northern Minnesota. *H. V. Winchell.* American Geologist, vol. xii, pp. 220–223, Oct., 1893.

Additional Facts about Nicollet. *H. V. Winchell.* Am. Geologist, vol. xiii, pp. 126–128, Feb., 1894.

A Bit of Iron Range History. *H. V. Winchell.* Am. Geologist, vol. xiii, pp. 164–170, March, 1894.

The Discovery of Mineral Deposits in the Lake Superior region. *H. V. Winchell.* Proc. Lake Superior Mining Inst., vol. ii, 1894.

False Bedding in Stratified Drift Deposits. *J. E. Spurr.* Am. Geologist, vol. xiii, pp. 43–47, Jan., 1894.

Oscillation and Single Current Ripple-marks. *J. E. Spurr.* Am. Geologist, vol. xiii, pp. 201–206, March, 1894.

The Iron Ores of the Mesabi Range. *J. E. Spurr.* Am. Geoligist, vol. xiii, pp. 335-345, pl. viii. May, 1894.

The Stratigraphic Position of the Thomson Slates. *J. E. Spurr.* Amer. Jour. Sci., III, vol. xlviii, pp. 159-166, Aug., 1894.

II.

LIST OF ROCK SAMPLES COLLECTED TO ILLUSTRATE THE NOTES OF N. H. WINCHELL, 1893.

1786. Coarse diabase, from a branching conspicuous dike, or bleb, which crosses, in part at least, the town site of Ely. It is seen on the highest portion of the town, cutting the bouldery graywacke, near the Catholic church.

1787. Amygdules, or pipe-like tubes, in the boulders or bombs of the agglomerate at Ely, filled with silica which appears to be "chalcedonic" or minutely granular. This new feature is found sparsely in the rock toward the southwest from the cut at the railroad already described. (Specimen lost).

1788. The diabasic rock mentioned under 1786 appears southwestward from the railroad cut, toward the Lockhart property (at Ely), and where it abuts against a bouldery mass of the graywacke or agglomerate, its grain and substance seem to enter the bouldery mass, at the same time becoming finer, and to surround the bombs, forming the dark-green scale which envelops them. This number, 1788, is a sample of the massive rock which enters, apparently, the graywacke and surrounds the boulder-like masses.

1789. An irregular, irruptive, siliceous rock, a kind of quartz porphyry. appearing in the midst of the greenstone on a knob about three-fourths mile west of the depot at Ely.

1790. Finely porphyritic or amygdaloidal diabase, like 1788, the amygdules (?) filled with a dark green mineral (chlorite ?), north from the Chandler mine, at Ely.

1791. In the conglomeritic portions of this greenstone, particularly in the matrix surrounding the boulders, is coarse silica, with calcite crystals, mingled in which are also isolated pieces of some green shale or scale, seen north from the Chandler mine.

1792. In some places the foregoing minerals (silica and calcite) become abundant, though very fine-grained, forming

lenticular masses of siliceous marble, which stand vertical. These are white, and from two to four inches thick and three or four feet long.

1793. Basal conglomerate, from the bottom of the supposed preglacial gorge, at Virginia. This is of ferruginous pebbles. mingled with dust and dirt of the iron bearing rocks. It may be of Cretaceous origin. It has a later infliltration of white silica which now forms its principal cementing bond.

1794. Forms of taconyte, showing transition from rock to ore, Moose mine near the line of separation from the Ohio, Virginia.

1795. Forms of the ore, Lone Jack mine, Virginia.

1796. Dark, diabasic rock which blends with the gabbro as if only a phase of the gabbro, at Duluth.

1797. Gabbro embracing small masses of augite-syenite, at Duluth, and containing as a result, numerous crystals of orthoclose as a constituent of itself.

1798. Siliceous pebbles or claystones from the Keewatin schists or slates about a mile and a half northeast of Otter Creek station, at the highway north of the St. Paul & Duluth railroad.

1799. Pebbles of disintegration from the gabbro at 1013 Michigan St., Duluth.

1800. Diabasic structure in the gabbro, thin plagioclase crystals lying parallel over large areas making a lath-shaped marking when weathered; same place as the last.

1801. Gneissic structure in the gabbro (rather a dioryte), taken at the point where the grand boulevard (running ap proximately on the upper beach) crosses a small creek back from Rice's point.

1802. Gabbro containing dark-green inclusions. These small dark-green masses are rather fine-grained and they seem to have affected the gabbro surrounding them by disseminating an element which, entering among the gabbro elements, has given rise to a red weathering feldspar and hornblende, along with some epidote. These dark-green spots, with the accompanying discoloration impart a noticeable spottedness to the gabbro mass wherever they occur.

1803. A fine-grained rock from the gabbro near the dam of the little creek where it is ponded above the grand boulevard, at Duluth.

1804. At a point midway between the dam and the elevated station of the elevated railroad, Duluth, is a large surface

exposure of some old metamorphic rock, some of it being brownish-red, and some of it gray. It is below the crest of the gabbro range, and on the southern slope, but is embraced within the general gabbro area. The red areas somewhat embrace the gray or blue. This number represents the red rock.

1805. Is the fine-grained gray rock. This is sometimes apparently a conglomerate, holding boulders of quartz and of granite, but in general it is a uniform rock. In some cases the red rock shades into the blue, even on the surface.

1806. Both of the above sometimes are amygdaloidal—at least are flecked with rounded dark-green spots about which are reddened areas resembling the inclusions in the gabbro, (1802).

1807. Samples from the sedimentary patches embraced in the amygdaloidal parts at Cow Tongue point, north shore of lake Superior.

1808. Pebbles from the hard fine grained, gray sedimentaries, got on the beach one mile west of Brulé river. They vary from blue to reddish, and one is white.

1809. Red rock pebble, from the same beach. These are usually amygdaloidal, and sometimes also porphyritic.

1810. Green doleritic trap pebbles from the same beach. These are very rare, although the rock outcropping on the shore, at all the points, consists of such trap.

1811. From the vertical cliff forming the west shore of Sickle bay—a rather fine-grained gabbro.

1812. Showing contact of this gabbro with a very fine-grained black rock, from a pebble on the beach.

1813. Poikilitic gabbro, from the west side of Double bay, at the point. The pyroxene shows its own sheen in the sunlight over large crystal surfaces.

1814. Gabbro from the hill range at Double bay, at the west end of the near hills.

1814A. White-weathering lumps and patches in 1814.

1815. In descending the hill again we encountered a slightly different phase, being very coarse with dark crystals of pyroxene and light-weathering large crystals of same plagioclase.

1816. Coarsely rough gabbro, at one mile east of Cannon Ball bay.

1817. Coarse gabbro, with poikilitic crystals of pyroxene, at a point two miles west of the west side of Red Rock bay.

1818. From the southern (basaltic) dike of the two trap dikes cutting the "red rock" on the eastern side of Red Rock bay.

1819. From the northern (non-basaltic) of the two dikes cutting the "red rock," at the same place, two feet from the contact with the other.

1820. Of the northern dike at the contact with the southern. These dikes are nearly parallel (east and west), but interfere with each other, the northern dike being the later.

1821. From a branching dike of diabase, or "black trap," at the extremity of Red Rock point. It has a pitted surface, from the decay and removal of some soft mineral.

1822. Quartz porphyry, Red Rock point.

1823. Sample from low rocky knob rising but little above the water, near the shore, within the bay next east of Red Rock point, but near Red Rock point, apparently underlying all the quartz porphyry.

1824. A curious, shaly-looking rock within the bay next east from Red Rock point, cut by conspicuous dikes that appear to be of the same age as those that cut the quartz porphyry.

1825. The same, having a spotted appearance.

1826. Amygdaloidal phases of 1824.

1826A. Agates from 1826.

1827. A metamorphic quartzyte, evidently some of the Wauswaugoning quartzyte, from the southern face of Mt. Josephine, about 500 feet above the lake.

1828. Basic irruptive rock concerned in the metamorphism of 1827.

1829. Average rock of the top of Mt. Josephine.

1830. "Red rock," kind of quartz porphyry, from a hill northwestward from Mt. Josephine, where it forms an irregular patch elongated about east and west, visible on the southern slope of the gabbro range.

1831. Conglomerate, from the east side of Grand Portage island.

1832. Darker and finer-grained sandstone(?), same place.

1833. From the very top of 1832, where it is in contact with an overlying trap sill.

1834. A peculiar, nearly black, amygdaloidal rock found on the very top of the island and extending westward gradually descending to the water level.

1834A. A lot of balls from 1834.

1834B. Series of red pebbles, from the beach of Grand Portage island.

1834C. Fine red granite, porphyritic with quartz, from a hill rising about 600 feet above the lake, about a mile and a half from Grand Portage, on the west of the Grand Portage trail. It is on one of the highest cliffs on the southern side of the hill, but forms only a small part of the hill, which consists rather of the gabbro of the region, being a part of the great dike range of which Mt. Josephine is a spur.

1835. Same contorted slate, from the low hill of slate, cut by numerous dikes, which rises near the lake at Grand Portage.

1836. A possible organic impression, from the slates of 1835.

1837. Upper portion of the Wauswaugoning quartzyte. It is gray, somewhat colored like the slates, spotted with light red, pink, or even green; from the foot of Mt. Josephine at the head of Wauswaugoning bay.

1838. The same, sub-crystalline, fine-grained.

1839. The same, having the form of quartz porphyry, appearing in patches in 1838, and also largely.

1840. The same, spotted with red and green.

1841. Plumbaginous quartzyte, from the old graphite mine on Pigeon point.

1841A. Spotted gray quartzyte, from the beach near the head of Morrison bay.

1842. At one-half mile west of Little Portage bay (*i. e.*, where Pigeon point is norrowest), the axis of Pigeon Point peninsula is composed of a dark-greenish but spotted modified quartzyte, the spots being coincident with or caused by poikilitic crystals of some rock-making mineral, apparently some feldspar.

1843. Gabbro, extremity of Pigeon point.

1844. Red rock, near the extremity of Pigeon point.

1845. Modified Wauswaugoning quartzyte, from the knob rising near the south shore of Pigeon point a little west of Little Portage bay—a quartz keratophyre, according to Bayley. This knob consists of various conditions of this quartzyte.

1846. Possible organic impressions in a limestone, septaria-like mass, weathered from the slates on the south side of the tongue which divides Pigeon bay into north and south arms.

1847. An amygdaloid with green fillings, at the eastern end of the outer and eastern of the Lucille islands.

1848. Massive pyroxenic rock, apparently in form of a dike, cutting 1847, same place.

1849. Porphyritic gabbro running diagonally, like a dike, across the same island.

1850. Red rock attached to 1849.

1851. Ore, from the Susie Island shaft, Pigeon Point Silver and Copper Mining company, an ill-starred enterprise inspired by the late T. M. Newson.

1852. Quartzyte and black slate, showing contact of sedimentary sequence in the shaft. It is apparent that while the shaft started in hardened slate at the surface, the excavation struck red quartzyte and finally red granite.

1853. Red granite from the bottom of the shaft.

1854. Black slate, at the Susie Island works, becoming crystalline with orthoclase and turning red on weathering.

1855. Sample of dike forming a little point about one mile west of the west point of Grand Portage bay.

1856. Amygdaloid cut by this dike.

1857. Amygdaloid, center of sec. 20, first point west of the last.

1858. Supposed sedimentary material containing laumontite, from the western side of Cow Tongue point.

1859. Red rock, not quartz porphyry, from the west side of Cow Tongue point.

1860. Quartz porphyry of the red rock series, on the S. town line of 62–1 E., where the new road from Grand Marais crosses it. This is also amygdaloidal, which is a new point in the petrology of this series.

1861. Coarse poikilitic gabbro, from the hills next north of the Brulé lakes, on the Iron trail.

1862. Finely granitic red rock, on the portage south from Misquah lake.

1863. Dark gray, or reddish-weathering fine-grained rock holding porphyritic crystals of feldspar, from the north side of Brulé lake at the portage north to Lost lake.

1864. Porphyritic orthoclase gabbro, S. W. ¼ sec. 13, T. 63-3 W., south shore of Brulé lake.

1865. A dark gray, rather fine-grained rock which is supposed to be derived from the porphyry series, S. W. ¼ sec. 14. T. 63–3 W. south shore of Brulé lake.

1866. Red rock porphyry. Probably S. E. ¼ sec. 15, 63–3, W.

1867. Orthoclase gabbro, S. E. ¼, S. W. ¼, sec. 24, T. 63–3 W.

1868. Red rock forming the hill in W. ½, N. E. ¼, sec. 25, T. 63–3 W.

1869. Fine grained orthoclase gabbro, south side of the island in N. E. ¼, S. W. ¼, sec. 24, 63-3 W.

1870. Peculiar gabbro, east end of the island, S. W. ¼, N. E. ¼, N. E. ¼, sec. 13, 63-3 W.

1871. Fine grained gray rock, with spots resembling amygdules. No structure made out in this rock; eastern point of the large island, N. E. ¼, S. W. ¼, sec. 18, T. 62-2 W.

1872. A phase of the same. These two specimens well represent the rock of this point.

1873. Red rock, fine grained and dark colored, N. E. ¼, S. E. ¼, sec. 18, T. 63-2 W. This is the eastern end of a range of red rock hills that lies on the south of Brulé lake in this $\frac{1}{16}$ section and S. ½, N. W. ¼, sec. 17.

1874. Dark porphyry, intermediate between the gabbro and the reddish porphyry (1863) seen about Brulé lake. South side of a small lake in the N. E. ¼, N. E. ¼, sec. 17, T. 63-2 W. The same is seen along the south shore ¼ mile further east.

1876. Dark, compact, fine grained rock, with a tendency to a reddish color. Small dark areas of crystalline material, surrounded by a vein of red which grades into the rest of the rock, are common, N. E. ¼, N. E. ¼, sec. 20, 63-3 W.

1877. Quartz porphyry, with black groundmass, in which are small quartzes and feldspars, the latter redish to flesh-color, and frequently having the outer part redder than the interior, N. E. ¼, N. W. ¼, sec. 20, T. 63-3 W.

1878. Quartz prophyry with dull red groundmass, small quartzes and red feldspars, which latter are not usually very distinct, as they are of about the same color as the ground mass, N. W. ¼, N. W. ¼, sec. 20, T. 63-3 W.

1879. "Black rock," so-called, on a small island in the N. W. ¼, S. E. ¼, sec. 18, T. 63-3 W.

1880. Spotted phase of the same, at the western outlet of Brulé lake, N. E. ¼, S. W. ¼, sec. 18, 63-3 W.

1881. Rather fine grained "pepper-and-salt" rock, in a low ridge crossing the trail from Brulé lake, S. W. ¼, N. W. ¼, sec. 18, T. 63-3 W., apparently in form of a dike.

1882. Fine grained red rock, from the precipitous cliff on the eastern side of the hill rising at the S. W. corner of sec. 8, T. 63-3 W.

1883. Hard "black rock," N. E. ¼, N. E. ¼, sec. 17, 63-3 W.

1884. Red "black rock," N. W. ¼, N. E. ¼, sec. 16, 63-3 W.

1885. Amygdaloid-like porphyry, from a reef-like island

just off the eastern most point in S. E. ¼. S. W. ¼, sec. 10, 63-3 W. The amygdaloidal spots are sometimes ½ inch in diameter.

1886. Black rock from the hills in the N. part of sec. 18, T. 63-3 W. at the west end of Brulé lake.

1887. A slaty fragment from the "black rock" forming a part of one of the hills in N. E. ¼ sec. 18, 63-3 W.

1888. Black rock, apparently with fine quartz grains. Same place as the last.

1889. Pseud-amygdaloid in the black rock, at the Temperance river outlet of Brulé lake.

1890. Apparently a coarse diabase, or a fine gabbro, possibly a derivative of the black series, cut by veins of red granite. Same place.

1891. Graphic granite, from veins and patches in the gabbro cut on the spur of the railroad near Paulson's camp.

1892. From an eighteen inch dike cutting the gabbro, seen on the railroad about a mile east of Paulson's camp.

1893. Fair sample of the iron ore at Paulson's, sec. 28, 65–4W.

1894. Pyrite, thought to contain nickel. Paulson's.

1895. An unknown mineral connected with the pyrite, from the quartzyte at Paulson's. This mineral is cinnamon colored.

1896. Average sample of an isolated ridge of Animikie saparated by a range of greenstone from the main mass of the Animikie, lying in S. W. ¼ sec. 21, 65-4 W., near Paulson's camp.

1897. Some of the finest portion of a singular slate-and-quartzyte breccia occurring in a low ridge by the railroad (south side), at the peat swamp crossing, about 1 mile west of the narrows of Gunflint lake.

1898. From the center of the conspicuous vertical dike which cuts the trap hill at the west side of the outlet of South Fowl lake.

1899. From the same dike from its contact with the trap forming the hill.

1900. Fair sample of the gray trap of the hill, remote from the dike.

1901. The trap near the dike, apparently changed to a greater denseness through the action of the dike.

1902. Fine quartzose conglomerate, overlying the next, dipping southward, toward the hill-range, from about the center of the N. W. ¼ of sec. 25, 64–4 E., southward from South Fowl lake.

1903. Lower portion of the conglomerate represented by 1902. These are each visibly about 18 feet thick, and grade into each other. The upper mass resembles the finer portions of the gritstone seen at the east end of Grand Portage island, and the lower one is like the coarse quartz-pebbly conglomerate seen near Fond du Lac in the valley of the St. Louis river.

1904. From the bottom of the perpendicular escarpment forming the top of the same hill. The hill rises about 350 feet above the country immediately north. This represents the top of the gritstone, and is similar to 1902. The gritstone has a thickness of about 126 feet, although it cannot all be seen exposed.

1905. From the top of the same hill, a non-descript rock resembling some Keewatin.

1906. A fine-grained member of the gritstone, from an exposure further east.

1907. Slate, south of the Millie mine, Iron Mountain, Mich.

1908. Limestone, "the limestone," same place.

1909. "Potsdam sandstone," unconformable over the limestone, same place.

1910. Typical jaspilyte of the Chapin mine region.

1911. Ore of the Chapin mine region, with "carbonate" interbedded.

1812. Rhodochrosite (?), Chapin mine ore dump.

1913. The conglomerate supposed to lie between the Millie and the Chapin, from the Quinnesec ore dump, from an old pit.

1914. Same of the schistose and calcareous portions of the greenstone, on the Wisconsin side, Lower Quinnesec falls, Menominee river.

1915. Some of the massive, ditto.

1916. Green schist, with quartz and carbonate of lime.

1917. Finely laminated, apparently sedimentary structure, in the green schists on the Michigan side, Lower Quinnesec falls.

1918. Coarsely crystalline, apparently gabbro-like rock thrown out in the excavation for the channel for running logs, Lower Quinnesec falls.

1919. "Actinolite-magnetite schist" and hematite, from the "lower Huronian," at a point in the first hill just south of the Republic mine, Michigan. Structure dips N. about 75 deg.

1920. Quartzyte, supposed to belong below the last, a little further south. The visible stratification here dips N. about 50 deg.

1921. Fine quartzose mica schist, in a narrow band visible about 18 feet, running in the granite, a little further south.

1922. Fine mica schist holding quartz pebbles, at the base, as supposed, of the "lower Huronian," lying on a granite which appears to be irruptive, and from which it is supposed to have derived boulder masses, about half a mile further south.

1923. Breccia of jaspilyte, cemented by dark jaspilyte, and by iron, Republic mine.

1924. Quartzyte, from the Republic ridge, at the point where the evident discordance occurs.

1925. From the same quartzyte, becoming sericitic, from an old mining location on the opposite side of the lake.

1926. Garnetiferous mica schist, from the same side of the lake but further west, a surface exposure thought to be from the top of the "upper Huronian."

1927. A much changed large dike of basic rock, running parallel with the strata in the "upper Huronian" at the railroad cut, west side of the lake.

1928. Conglomerate containing copper, Calumet and Hecla mine.

1929. A boulder-like mass, containing a large amount of copper, apparently a boulder of amygdaloid or other porous rock which has received copper into its interstices, same place.

1930. "Shot copper," originally an amygdaloidal fragment of some eruptive rock embraced in the general conglomerate, has been permeated by metallic copper from solution, same place.

1931. String copper, with a little silver, from which the associated boulders have been separated.

1932. Calcite crystals, containing interleaved copper; same place.

1933. "Half breed", i. e. mass of metalic copper containing some silver, found under the stamps. Calumet and Hecla.

1934. "Baby ingot" of metallic copper. Calumet and Hecla.

1935. Sandstone having a matrix of metallic copper. Calumet and Hecla.

1936. "Melaphyr" trap, taken from the Tamarac shaft, near the Calumet and Hecla mine, the most abundant rock passed through in the 3,000 ft. New shaft.

1937. Variation of this trap rock, with some epidote.

1938. Carbonate, supposed to be that from which the iron

ore of the Palms mine (near Ironwood, Mich.), and of the Gogebic range in general, is derived. From near the Palms mine.

1939. Tufaceous material, in the "upper Huronian", interbedded with the iron-bearing rocks. From tne dump at the Palms mine.

1940. The siliceous slate south of the Aurora mine, involved in the granite, whether by irruptive contact or by sedimentary non-conformity, is a point of difference.

1941. The granite here contacting.

1942. Some of the poikilitic, most coarsely crystalline portion of the gabbro at the first railroad cut (most westerly) near Short Line park, on the St. Paul & Duluth R. R. From the east end of the cut. Much of this rock at the first cut is amygdaloidal, especially toward the western end of the cut, and on the western face of the hill, and most of it is rather a green trap or diabase, when not amygdaloidal.

1943. Very fine-grained, dense, olivinitic gabbro, weathers greenish. From the second cut east of Short Line park, (on the E. line of S. E. ¼ sec. 33).

1944. The usual black irony belt in the gabbro hill at the same place, visible on the west face of the hill.

1945. Coarse olivinitic, magnetited gabbro. Same place.

1946. Underlying coarse gabbro, same place.

1947. From veins, or seams, in 1946, same place.

1948. Highly blackened gabbro, from another cut further east, probably in the east side of sec. 34. This is rather fine grained but not observably magnetic. It constitutes but a small part of the prevailing rock.

1949. From a detached amygdaloidal mass between the depot and the river at Cloquet.

1950. Average type of the gabbro of the first (westerly) hill range, in sec. 33, near Short Line park.

1951. Three samples showing the average amygdaloidal structure in the same hill.

1952. One of the narrow amygdaloidal dikes cutting this hill, with contact on the gabbro, same place.

1953. From a large dike running N. 15 deg. E., same place.

1954. Massive homogeneous, irruptive rock mingled with the bombs and graywacke in the "greenstone formation" near (but north from) the depot at Ely. (Specimen lost.)

1955. Concretionary, rounded small masses, resembling those figured on p. 318 of the 16th annual report, from the

ambiguous greenstone at Ely, near the Catholic church. (Specimen lost.)

1956. A breccia embracing some green fragments of the schist.

1957. Sub-crystalline porodyte, or feldspathic quartzyte, north side of Ely island, Vermilion lake. With the exception of a little argillyte at the west end of this island the whole north shore consists of rock of this kind.

1958. Apparently burnt jaspilyte, from the mainland southeast from Ely island. This appears as a black, slaty argillitic jaspilyte, in the midst of porodyte, and runs at least one-fourth mile, with the usual strike, standing nearly vertical, or dipping 85–90 deg. toward the north.

1959. Three pieces showing the south contact of this on the porodyte. No effect, so far as can be seen, is produced on either; but the porodyte simply becomes some finer and greener. We subsequently noted the same contact on the north side of a jaspilyte belt, with the same result.

1960. Some squeezed masses of jaspilyte showing the changed forms of pebbles of different colors. North side of the north ridge, at Soudan.

1961. Apparently pebbles, pressed, enclosed in hematitic jaspilyte, but on close examination they appear to be remnants of reddish jaspilyte replaced otherwise by hematite.

1962. A form of the greenstone which appears on the north slope of the "north ridge." It has an approach toward argillyte.

1963. A black slaty jaspilyte is seen near the limonite locality, where a large amount of limonite was taken out by the Minnesota Iron company but not shipped, north from Soudan. Is it carbonaceous?

1964. Another coarse, siliceous grit, or quartzose graywacke, weathering light-colored, embraced in the argillytes, and interbedded with them, yet owing to upheaval and fracture now forming all manner of contact with them, from the west side of a point within the bay about a mile and a half west of Stuntz island, south shore of Vermilion lake.

1965. Similar to the last, but also resembling much of the rock on Stuntz island, from the same point, but a little nearer the extremity of the point.

1966. A typical homogeneous specimen of the "black rock," so-called, at the crossing of Lake street and Piedmont avenue, Duluth.

1967. A sample of the conglomerate-appearing portion of the same black rock near the same place.

1968. Red rock, associated with this black rock near the creek crossed by Piedmont avenue a short distance further west.

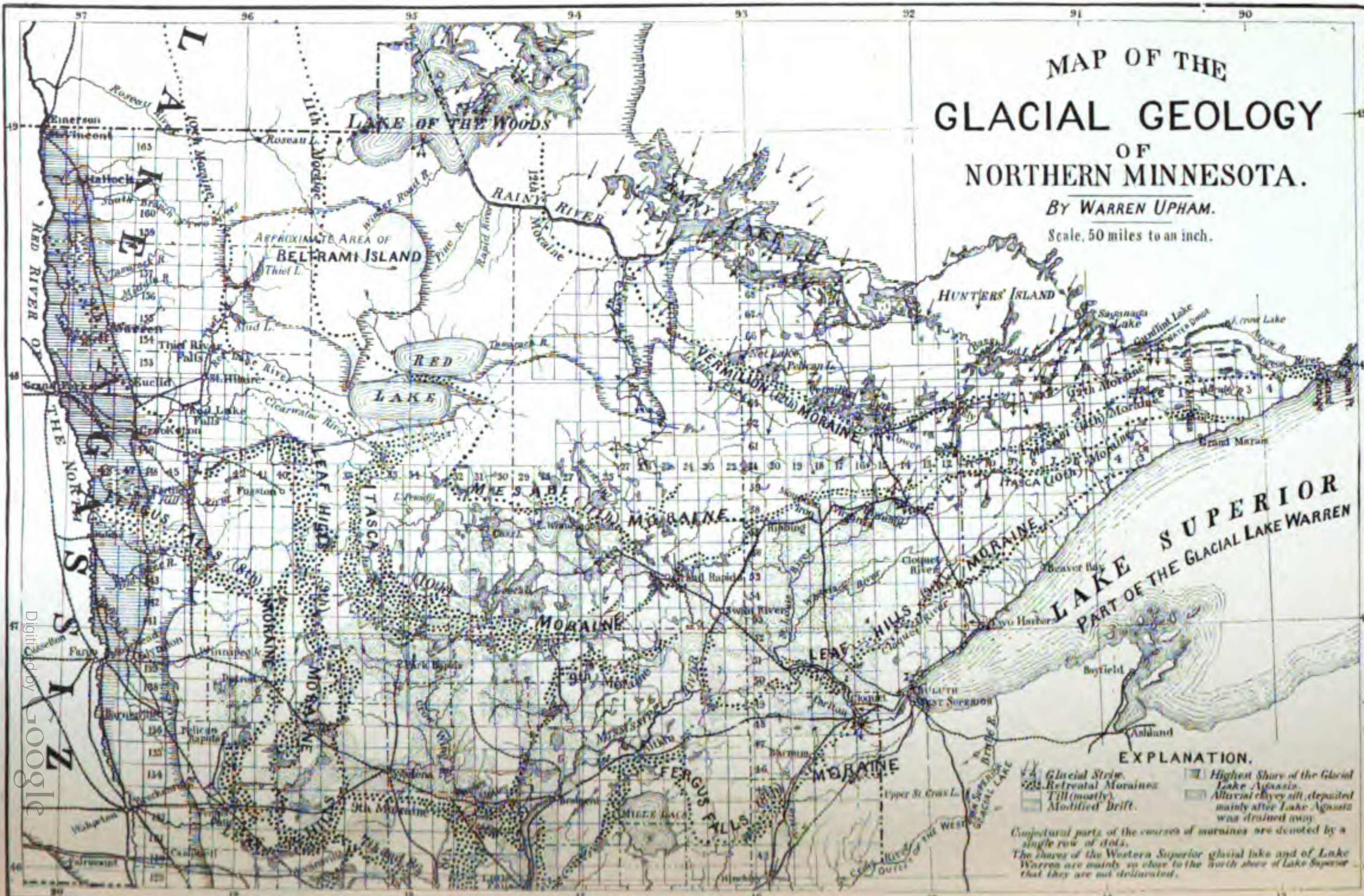
[NOTE. The descriptive observations and diagrams accompanying these specimens, as made in the field, are reserved for use in the final report.]

III.

PRELIMINARY REPORT OF FIELD WORK DURING 1893 IN NORTHEASTERN MINNESOTA, CHIEFLY RELATING TO THE GLACIAL DRIFT.

By WARREN UPHAM.

CONTENTS.


MAP OF THE
GLACIAL GEOLOGY
OF
NORTHERN MINNESOTA.
BY WARREN UPHAM.
Scale, 50 miles to an inch.
LAKE AGASSIZ
LAKE OF THE WOODS
RAINY RIVER
RAINY LAKE
12th Moraine
11th Moraine
10th Moraine
APPROXIMATE AREA OF
BELTRAMI ISLAND
RED LAKE
HUNTERS' ISLAND
VERMILION (12th) MORAINE
MESABI (11th) MORAINE
ITASCA (10th)
LEAF HILLS (9th) MORAINE
ITASCA (10th) MORAINE
FERGUS FALLS (8th) MORAINE
LEAF HILLS MORAINE
FERGUS FALLS MORAINE
LAKE SUPERIOR
PART OF THE GLACIAL LAKE WARREN
RED RIVER OF THE NORTH
Grand Marais
Two Harbors
Duluth
Ashland
Bayfield
Emerson
Pembina
St. Vincent
Hallock
Warren
Thief River Falls
Red Lake Falls
Crookston
Grand Forks
Fargo
Moorhead
Fergus Falls
Wahpeton
Roseau R.
Tamarack R.
Clearwater River
Mississippi R.
EXPLANATION.
Glacial Striæ.
Retreatal Moraines.
Till (mostly).
Modified Drift.
Highest Shore of the Glacial Lake Agassiz.
Alluvial clayey silt, deposited mainly after Lake Agassiz was drained away.
Conjectural parts of the courses of moraines are denoted by a single row of dots.
The shores of the Western Superior glacial lake and of Lake Warren are mainly so close to the North shore of Lake Superior that they are not delineated.

AREAS EXAMINED.

From June 6th to November 2d, the writer was engaged in field work in the north central and northeastern portions of Minnesota, excepting absence during the second half of August in attendance at the sessions of the Geological Society of America and the American Association for the Advancement of Science, in Madison, Wis., and of the World's Congress on Geology, auxiliary with the Columbian Exposition, Chicago. The areas specially assigned to me for examination and report comprise (1) Aitkin county; (2) Cass county (excepting the small part north of Hubbard county, assigned to Prof. J. E. Todd); and (3) the large tract of Crow Wing county lying northwest of the Mississippi river (which at the time of the writing of chapter XXII in volume II of the Final Report of this Survey, treating of Crow Wing and Morrison counties, was included in Cass county, being transferred thence to Crow Wing by the state legislature in 1887).

After the examination of these areas, which occupied the summer months, my work during September and October consisted of observations of the glacial and modified drift in the vicinity of Moose Lake, Barnum, Carlton, and Duluth; southwestward from Duluth and West Superior to Holyoke, on the Eastern branch of the Great Northern railway; northwestward along the Duluth and Winnipeg railroad from Duluth to Grand Rapids; along the Duluth and Iron Range railroad for the entire extent of its main line from Duluth to Two Harbors, Tower, and Ely, and on its Western Mesabi branch from Allen Junction to Biwabik; and along Vermilion lake, from Tower to its outlet and western end.

MAPPING ACCOMPLISHED.

Having the township plats of the government surveys as the basis for topographic (or hypsometric) and geologic mapping, the delineations to be added were (1) lines of contour, showing the form of the land surface in undulating or rolling tracts, hills, valleys, and plains, with the altitudes of all portions above the level of the ocean; and (2) the location of rock outcrops, and the extent and boundaries of the diverse drift deposits.

I. TOPOGRAPHY.

For the reference of the contour lines to the sea level, the hights determined by the surveys for the railroads of this part

of the state, all of which north of Duluth and the Northern Pacific railroad have been recently constructed, were obtained by copying from the profiles of these surveys. Every facility for this was courteously granted by the officers and engineers of the several railroad companies, namely, the Duluth & Winnipeg, the Duluth, Missabe & Northern, and the Duluth & Iron Range; and likewise of the shorter railroads used chiefly or wholly for lumbering purposes, namely, the Brainerd & Northern Minnesota railway, the Mississippi & Northern railroad (running northward from Cross lake, Crow Wing county), and the Duluth, Mississippi River & Northern railroad (running northward from Hiawatha, at the mouth of the Swan river). Previously I had similarly obtained and published the altitudes determined by the Northern Pacific railroad; the St. Paul & Duluth railroad; the Eastern railway of Minnesota (operated by the Great Northern railway company); and hights of the Mississippi and St. Louis rivers, and of lakes about their sources, as shown by these various railroad lines and by surveys of U. S. Engineers for the purpose of constructing reservoirs on the upper Mississippi and its tributaries.*

Using these altitudes, exactly ascertained by levelling, as data for reference, careful observation and barometric readings have sufficed for the drafting of the lines of contour, 50 feet apart vertically, upon the areas here reported. Mainly the surface is nearly level or only moderately undulating, but in certain belts it rises prominently in hills 50 to 200 feet or more in hight, consisting of marginal morainic drift accumulations which mark the boundaries of the ice-sheet at stages of pause or slight re-advance interrupting its general retreat at the close of the Glacial period. The valleys of the rivers are seldom very deeply eroded below the general level, their depths ranging from 10 or 20 feet to 100 feet or rarely more. Similarly shallow or sometimes deep depressions in the general sheet of drift hold the numerous or often very abundant lakes, which lie commonly 10 to 40 feet below the surrounding country, and have depths of 10 to 50 or 75 feet or rarely more.

In Aitkin, Cass, and Crow Wing counties, outcrops of the bed rocks are very rare. The thickness of the overlying drift is believed, from its known depths in other parts of the state, to vary from 50 or 75 feet to 150 or 200 feet, or perhaps

* "Altitudes between Lake Superior and the Rocky Mountains," forming Bulletin No. 72, U. S. Geol. Survey, 1891, pp. 229.

occasionally more, being spread as a somewhat uniform sheet over that region. The general altitude and slopes of the land are therefore due to the form of the rock floor on which the drift rests. In the neighborhood of Carlton and Duluth, however, and on many large tracts of the country farther north and northeast, the bed rocks have abundant exposures, and bold rock hills and cliffs often show more evidently the part which the rocky foundation takes in all the grand topographic features.

The following table contains altitudes of the more important railroad stations, lakes, rivers, and hills, in the region of this report, noted in feet above mean tide sea level.

Altitudes above the Sea Level.

RAILROAD STATIONS (track).

St. Paul & Duluth Railroad.

	Feet.
Duluth	608
Short Line Park	875
Thomson	1055
Carlton	1083
Otter Creek station	1150
Summit of grade, about 1 mile north of Mahtowa, highest on this railroad	1170
Mahtowa	1147
Barnum	1105
Moose Lake station	1063

Great Northern Railway.

West Superior	631
South Superior	672
Boylston	687
Dedham	802
Foxboro	956
Rhodes' Mill	1025
Holyoke	1100

Northern Pacific Railroad.

	Feet.
Duluth	608
South Superior	672
Pokegama	682
Walbridge	815
Barker	953
Wrenshall	1044
Summit of grade, 1½ miles southeast of Carlton, in a rock cut 18 feet deep	1098
Carlton	1083
Pine Grove	1237
Sawyer	1317
Cromwell	1306
Wright	1309
Tamarack	1271
McGregor	1228
Kimberly	1237
Rossburg	1222
Aitkin	1208
Cedar Lake station	1222
Deerwood	1277
Jonesville	1238
Brainerd	1209
Baxter	1205
Gull River station	1191
Sylvan Lake station	1207
Pillager	1203
Wheelock	1214
Motley	1227
Hayden	1255
Staples	1274

Duluth & Winnipeg Railroad.

Cloquet	1191
Nagonab	1214
Stony Brook station	1230
Stony Brook Junction	1226
Catlin	1237
Floodwood	1255
Island	1267
Wawina	1268
Swan River station	1293
Blackberry	1300
La Prairie	1283
Grand Rapids	1287

	Feet.
Cohasset	1284
Deer River station	1291

Duluth, Missabe & Northern Railway.

Shops	1230
Pine	1358
Grand Lake siding	1332
Burnett (at the Cloquet river)	1295
Columbia	1267
Albert	1301
Birch	1320
Kelsey (at the Whiteface river)	1302
Wallace	1316
Morrell	1333
Shaw (at the St. Louis river)	1339
Iron Junction	1379
Wolf	1402
Mountain Iron	1450
Hibbing	1565
Virginia	1439
Eveleth	1505
Biwabik	1455

Duluth & Iron Range Railroad.
Main Line.

Duluth	608
Lester Park	651
Clifton	661
Arthur	663
Two Harbors	692
Waldo siding	1057
York siding	1450
Highland	1709
Summit of grade, highest on this railroad, about 1 mile north of Highland, in a cut of morainic till 20 feet deep	1744
Thomas siding	1610
Cloquet River station	1504
Breda siding	1580
Bassett Lake station	1636
Reno siding (summit of grade)	1676
St. Louis River station	1584
Allen Junction	1508
Mesaba	1513
Hinsdale siding (summit of grade)	1596
Embarras River station	1426
Norway siding	1472
West Two Rivers siding	1426
Tower Junction	1381
Tower	1367
Armstrong Lake siding	1475
Robinson Lake station	1482
Ely	1417

Western Mesabi Branch.

Allen Junction	1508
Biwabik	1458
McKinley	1436
Virginia station (¼ mile east of the town and about 115 feet higher)	1555

LAKES.

Lake Superior, low and high water, 600-603; mean 1870 to 1888	601.56

*Along the International Boundary.**

South Fowl lake	1436
North Fowl lake	1440
Moose lake	1492
Mountain lake	1652
Rove lake	1667
Watershed on the boundary, between sources of the Pigeon and Arrow rivers, about	1715
Rose lake	1528
South lake	1558
North lake	1550
Gunflint lake	1547
Pine lake	1465
Granite (or Banks' Pine) lake	1448
Saganaga lake	1434
Swamp (or Oak) lake	1435

*From the profile, principally based on levelling, of the "Route by the Grand Portage and Pigeon River from Lake Superior to Rainy Lake," in S. J. Dawson's "Report on the exploration of the country between Lake Superior and the Red River settlement, and between the latter place and the Assiniboine and Saskatchawan," Toronto, 1859 (pp. 45, with two maps and two profiles); corrected approximately to accord with the recent survey of the Port Arthur, Duluth & Western railway, giving the altitude of Gunflint lake, and with the altitudes of Knife, Carp, Sucker, and Basswood lakes, which, as given in this series, besides many others south and southeastward to the Devil's Track lake, were determined in 1893 through levelling by L. A. Ogaard and Alex. N. Winchell for the Geological and Natural History Survey of Minnesota.

	Feet.
Watershed between Saganaga and Otter Track lakes, crossed by a portage of ¼ mile, the only exception to a complete circuit of lakes and streams enclosing "Hunters' Island," about	1475
Otter Track (or Cypress) lake	1387
Knife lake	1382
Carp (or "Pseudo-Messer") lake	1355
Sucker (or Birch) lake	1330
Basswood lake	1300
Crooked lake	1245
Lac la Croix (Nequauquon lake)	1186
Crane, Sand Points, and Namekan lakes	1127-1126
Rainy lake, low and high water, 1115-1120; mean	1117
Lake of the Woods, low and high water, 1057-1063; mean	1060

South of the International Boundary.†

	Feet.
Red lake	1172
Lake Itasca	1464
Lake Pemidji	1355
Cass lake	1300-1302
Lake Winnebagoshish, formerly, 1290-1293; as raised by dam of reservoir system	1298
Bow String lake, head of the Bow String river (or Big Fork of Rainy river)	1321
Ball Club lake	1281
Bass lake	1275
Leech lake, formerly 1293-1295; as raised by dam of reservoir system	1297
Kabecona lake	1302
Pokegama lake, formerly 1271; as raised by dam of reservoir system	1275
Sandy lake, formerly 1211; proposed highest flowage by dam of reservoir system	1220
Mille Lacs, low and high water, 1249-1254; mean	1251
Cross and White Fish lakes, as raised by dam of reservoir system	1231
Maximum capacity of this dam	1236
Little Boy lake	1309
Wabado lake	1312
Woman and Girl lakes	1324
Ten Mile lake	1378
Fourteen Mile lake	1375
Crow Wing lake, at the head of Crow Wing river	1390
Eighth or Prairie lake, Crow Wing river	1385
Seventh, Sixth and Fifth lakes of this river, respectively 1382, 1379 and 1378.	
Elbow lake	1426
Long lake, Hubbard county	1364
Sylvan lake	1201
Lower and Upper Gull lakes, as flowed by dam	1200
Lake Hubert	1199
Long lake, Crow Wing county	1198-1200
Pelican lake, Crow Wing county	1211
Embarras lakes	1380-1353
Vermilion lake	1357-1360
Trout lake, close north of last, about	1370
Burnt-side lake, also about	1370
Long lake,* Ely	1337
Fall lake*	1313
Newton lake*	1307
Garden or Eve lake‡	1384
Farm lake	1386
White Iron lake	1395

†These altitudes from Red lake to Vermilion lake, inclusive, are from levelling, mostly by railroad surveys, but along the upper Mississippi by United States engineers for the system of reservoirs, and, in the case of lake Itasca, by J. V. Brower, Commissioner of the Itasca State Park (to whose published altitude seven feet are here added, as required by the corrected elevation of the Great Northern railway at Park Rapids).

*From levelling for this Survey in 1893, by L. A. Ogaard and U. S. Grant. The altitudes of Trout and Burnt-side lakes, and of others following, when not specially indicated, are from barometric readings by Prof. N. H. Winchell, Dr. U. S. Grant and Mr. A. H. Elftman, referred to sea level approximately by comparison with the hights ascertained by levelling.

‡From surveys for extension of the Duluth & Iron Range railroad.

	Feet.
Birch lake	1410
Slate lake (T. 60, R. 10)	1640
Greenwood lake (T. 58. R. 10)	1705
Seven Beaver lake	1675
Gabbro lake	1464
Bald Eagle lake	1468
Lake Isabelle	1570
Snowbank lake†	1424
Wilder lake	1540
Lake Alice	1544
Thomas lake	1534
Fraser lake	1535
Kekequabic lake*	1497
Syenite lake (T. 62, R. 6 W.)	1777
Lake Polly (T. 63, R. 6 W.)	1617
Little Saganaga lake*	1600
Gabemichigama lake*	1587
Ogishke Muncie lake*	1488
Sea Gull lake	1440
West Sea Gull lake	1455
Lake Ida Belle*	1793
Kiskadinna lake*	1767
Mayhew and Iron lakes*	1853
Loon lake*	1745
Brulé lake*	1851
Winchell lake*	1910
Gaskanas lake*	1878
Meeds lake*	1879
Lake Abita, probably the highest in the state, on the southern slope of Brulé mountain*	2048
Devil's Track lake*	1636

RIVERS.

Mississippi river.

NOTE.—See lakes Itasca, Pemidji, Cass, and Winnebagoshish, in the preceding list.

	Feet.
Head and foot of Pokegama falls, as raised by dam	1275-1254
Head and foot of Grand rapids, ½ mile long	1253-1248
Mouth of Split Hand river	1236
Mouth of Swan river	1226
Mouth of Sandy river, low and high water	1210-1224
At Aitkin, low and high water	1190-1200
Mouth of Pine river, ordinary low stage	1177
At Rice lake, two miles north-east of Brainerd, held by dam	1172
At Brainerd, low and high water	1150-1167
Mouth of Crow Wing river, low and high water	1145-1163
At Little Falls, above and below the dam	1099-1079
At St. Cloud, above and below the dam	975-960
At Minneapolis, above and below St. Anthony's falls	794-738
At St. Paul, low and high water	683-702

Crow Wing river and its tributaries.

NOTE.—The hights of Crow Wing and lower lakes, forming a series on the head stream of the Crow Wing river, are given on page 23.

The survey of the Great Northern railway branch to Park Rapids supplies the following altitudes of tributaries of the Crow Wing river at the bridges of this railway:

	Feet.
Leaf river	1293
Blueberry river	1372
Shell river	1379
Straight river	1402
Fish-hook river	1424
Crow Wing river at Motley	1208
Junction of Crow Wing river with the Mississippi, low and high water	1145-1163

St. Louis river and its tributaries.

	Feet.
Embarras river at bridge of the D. & I. R. railroad	1410

*From levelling for this Survey in 1893, by L. A. Ogaard and U. S. Grant. The altitudes of Trout and Burnt-side lakes, and of others following, when not specially indicated, are from barometric readings by Prof. N. H. Winchell. Dr. U. S. Grant and Mr. A. H. Elftman, referred to sea level approximately by comparison with the hights ascertained by levelling.

†From surveys for extension of the Duluth & Iron Range railroad.

Feet.

Lakes of this river, extending in a series about 12 miles, where it passes through the Giant's (or Mesabi) range and southward..............1380-1353

Cloquet river at bridge of the D. & I. R. railroad...........1479

Small lakes forming the head of the St. Louis river, in the west part of T. 59, R. 11 W., about........................1685

Expansion of this river in Seven Beaver lake..................1675

St. Louis river at bridge of the D. & I. R. railroad.......... 1584

At bridge of the D., M. & N. railway......................1300

At mouth of Floodwood and East Savanna rivers.........1234

At Stony Brook Junction......1211

At Cloquet, head of rapids above Knife falls...................1178

Foot of Knife falls.............1160

At bridge of the D. & W. railroad 1120

Top of dam at Thomson, about.1040

At bridge of the St. P. & D. railroad, close below the last, low and high water 997-1020

At Fond du Lac, level with lake Superior, about seven miles east of Thomson............. 602

Hills and Mountains.

Highest point on the road from Brainerd to Leech lake, about seven miles south of the Indian Agency.................1500

Summit of ridge southwest of Pokegama lake, in the south part of T. 54, R. 26, the highest point in Itasca county....1617

Poquodenaw mountain, sec. 25, T. 52, R. 26, the highest hill in Aitkin county, about......1525

Feet.

Hills in secs. 26 and 28, T. 59, R. 17, about four miles northeast and three miles N. N. E. from Virginia, forming the highest land in St. Louis county, respectively, about....2025 and 2150

Summits of the Giant's (or Mesabi) range, in T. 59, R. 16, a few miles north of Biwabik...... 1800-1900

Summits of this range near Hinsdale, where it is crossed, in a gap, by the D. & I. R. railroad.................1850-1950

Hill close north of Tower (South ridge), about..........1560

Soudan hill (North ridge), one mile northeast from the last, about........................1600

Jasper peak, 2¼ miles east of Tower, about................1650

Ridge close southeast of Syenite lake, in the east part of T. 62, R. 6 W., probably the highest in Lake county, about..2100-2200

Misquah hills, Cook county, the highest in Minnesota, in the south edge of Ts. 64, Rs. 1 and 2 W., comprising several summits about 2200 feet above the sea along a distance of eight miles from east to west, with their highest point about a half mile southeast from the east end of Winchell lake, determined by levelling.2230

Brulé mountain (T. 63, R. 1, W.), by levelling.............2170

Top of bluffs (600 to 700 feet above lake Superior) close north of Duluth........1200-1300

Sawteeth mountains, near the shore of lake Superior, from Temperance river and Carlton's peak to Grand Marais 1300-1700

II. GEOLOGY.

In the areas assigned to me for geologic mapping and report, namely, Aitkin and Cass counties, and the northwestern part of Crow Wing county, the tracts covered by the several varieties of the glacial and modified drift have been delineated approximately. The few and small outcrops of the bed-rocks have also been shown on the maps; but, in a region so almost universally drift-covered, it is impossible to trace with certainty, or perhaps even with demonstrable probability, the limits of these Archean and Taconic formations. Under many portions of the drift-sheet here Cretaceous beds, though not observed in outcrops, are doubtless still thinly represented in place. On a map of the formations underlying the drift, the northwestern part of Cass county is best shown as Cretaceous, and this may also extend eastward through Aitkin county; for it is known that much of the drift of these counties has been derived from contiguous and underlying Cretaceous shales by glacial erosion.

SKETCH OF RESULTS OF GEOLOGICAL WORK.

I. ARCHEAN OUTCROPS IN AITKIN AND CASS COUNTIES.

A considerable tract in the southeastern part of Aitkin county is probably occupied by Archean rocks, which extend thence east and south into Pine and Kanabec counties. Between the Snake river and Cowan's brook, in the south edge of Aitkin county, the glacial drift in the S. E. ¼ of sec. 34, T. 43, R. 23, has in some places very plentiful blocks of a fine-grained, gray granite, containg black mica. This Archean formation is doubtless the bed-rock there at a little depth below the surface. Within a mile southwestward, and thence for nearly three miles down the Snake river, past its Upper and Lower falls in northern Kanabec county, Archean granites, schists, and gneiss, have many and extensive outcrops.

In the most southwestern township (T. 134, R. 32) of Cass county, the east half of sec. 28, about five miles northwest from Motley, comprises an area of frequently outcropping hornblendic granite, extending a half mile from south to north, with a width of twenty to forty rods. These rock exposures rise five to eight feet above the adjoining general surface of moderately undulating drift, being twenty to forty feet above the Crow Wing river, which lies about three-fourths of a mile to the southwest. Two wide dikes of dark, tough diabase in-

tersect the granite, following the course of nearly vertical joint planes. In the Eleventh Annual Report (pages 87, 88), these rocks are described in detail, and a figure is given showing a part of one of the dikes, with narrow branches running from it. Some portions of this granite may be found valuable for quarrying, which, though several times contemplated, has not yet been undertaken.

II. QUARTZYTE AND DIABASE IN AITKIN COUNTY.

Quartzyte forms a slightly projecting point of the northwestern shore of Dam lake, near the center of the west half of sec. 35, Kimberly (T. 47, R. 25), about three miles south from Kimberly station and eleven miles east of Aitkin. Its outcrop has a length of about 250 feet along the shore and varies in width from 15 to 50 or 60 feet, rising to a hight of four or five feet above the lake. Through all its extent the rock is much fractured into separate boulder-like masses from one or two feet up to ten or rarely twelve feet in diameter, lying in close contact, with only very scanty foreign drift boulders of granitic, trappean, and other crystalline rocks such as abound in the drift of all this district, and even in the immediate vicinity of the outcrop. Boulders of the quartzyte, however, are very rare in the drift, and the great abundance of its masses at this locality shows unquestionably that it is here the bed-rock, although no compact ledge is seen. The shattered condition of its whole observable extent seems probably attributable to preglacial weathering of the rock at and near this place to form low cliffs with many boulders due to gradual disintegration along crevices and joint planes. During the Glacial period some or perhaps all of these quartzyte masses may have been transported short distances, but the very small proportion of boulders of other rocks mingled with the quartzyte indicates that its blocks are in or near their preglacial position.

In its original condition this rock was a sandstone of well-rounded white quartz grains mostly from a thirtieth to a tenth of an inch in diameter. The spaces between the grains have become filled with similar white quartz, and the rock is now a very compact light gray quartzyte, varying rarely in superficial portions to a partially reddish color where iron peroxide coats the sand grains and stains the interstitial quartz.

Apparently the most probable hypothesis that we can assume, in attempting to correlate this Aitkin county quartzyte with the stratigraphic sequence of rock formations ascertained

elsewhere in all the surrounding country, is to suppose it to be a part of some area, very probably a belt having a general east-northeast to west-southwest extension, of the Pewabic formation, which is regarded as the basal member of the Taconic series. There may be, according to this hypothesis, a wide and shallow synclinal trough of the quartzyte with its northern border on the southern slope of the Giant's (or Mesabi) range, with western continuation to Pokegama falls on the Mississippi, and its southern rim represented by the locality here described. The dip and strike of the strata, however, were not determinable in this place, since no distinct lines of bedding were observed in any of these quartzyte masses; and their irregular forms, although evidently due to joint structure, indicate that the formation here is not traversed by any regular systems of parallel and intersecting joints.

About three miles southwest from this exposure of quartzyte, two outcrops of nearly black, rather coarse-grained, very hard and tough diabase occur in the S. W. ¼ of sec. 9, T. 46, R. 25, within about a fourth of a mile west from the south end of Long lake and some 20 or 25 feet above it. A foot trail leading from Rabbit lake northeasterly to Dam lake passes over the western and larger outcrop, which has a smooth and somewhat flat extent of about 100 feet from southwest to northeast, with a maximum width of 30 feet, rising only one to two feet above the general surface of the glacial drift. This trap rock shows no traces of flow or shear structure, nor any noteworthy variation in the degree of coarseness of its crystalline texture, throughout its visible area. It belongs doubtless to the central portion of a dike of undetermined but probably not very great width, whose borders and contact with the country rock on each side, presumably quartzyte, are hidden by the drift.

The course of the dike is probably from southwest to northeast, for a second exposure of the same rock is found at a distance of about twenty rods farther northeast, divided from the foregoing by a slight depression of five feet in which there is a grove of several large poplars. The length of this outcrop is about 30 feet, also trending northeastward, and its width 15 feet. Both outcrops are cut in many directions by numerous joints, nearly vertical or steeply inclined, among which no prevailing system is observable. Slight weathering of these rock surfaces has removed their glacial striation; but the diabase appears to have been more durable to resist decay than the

enclosing strata of the country rock, for which reason the dike remains with a greater hight and projects through the drift sheet. A wooded hill of the drift rises within a distance of about a quarter of a mile northeastward to a hight of 40 feet or more above the trap outcrops, which lie in a tract having only bushes and scattering small trees. An examination for a considerable distance around failed to discover other rock exposures, but very probably some of small extent will be found if the land should be cleared for cultivation or pasturage.

The time of the volcanic or more deeply seated plutonic intrusion of the trap rock here cannot be definitely stated. Quite probably it may have been contemporaneous with the intrusive laccolitic sills of diabase in the Animikie and Keweenawan (or Nipigon) sedimentary formations on the northwest coast of Lake Superior. Dr. A. C. Lawson concludes that those trap sheets and dikes, mostly similar to the diabase in Aitkin county, are of some undetermined age subsequent to the Keweenawan period, which was in the later part of the Taconic or Algonkian era.* They may belong, however, to a very late stage of this era, before its great upper series of detrital and volcanic rocks was completed.

III. EVIDENCE OF CRETACEOUS BEDS UNDERLYING THE DRIFT.

Although no outcrops or natural exposures of Cretaceous strata have been found in Aitkin and Cass counties, it seems highly probable that shales of this age remain in many places, perhaps upon the greater part of this area, beneath the drift. Fifteen years ago Prof. N. H. Winchell wrote:

> A line drawn from the west end of Hunters' Island, on the Canadian boundary line, southward to Minneapolis, and thence southeastwardly through Rochester to the Iowa state line, would, in general, separate that part of the state in which the Cretaceous is not known to exist from that in which it does. It is not here intended to convey the idea that the whole state west of this line is spread over with the Cretaceous, because there are many places where the drift lies directly on the Silurian or earlier rocks; but throughout this part of the state the Cretaceous exists at least in patches, and perhaps once existed continuously.†

This opinion has been well confirmed by the subsequent work of this Survey, and notably by Mr. H. V. Winchell's recent discoveries of Cretaceous shales at several places 35 to 45 miles northeast of Aitkin county, along the elevated Mesabi range.‡ The Cretaceous marine submergence of this region

*Bulletin No. 8, of this Survey.

†Bulletin of the Minnesota Academy of Natural Sciences, vol. i, p. 348.

‡Am. Geologist, vol. xii, pp. 220-223, Oct., 1893.

appears thus to have extended eastward at least to the present site of lake Superior. A large part of the clay of the glacial drift here was doubtless derived by erosion from Cretaceous shales, and their calcareous matter supplied to the drift may principally account for its small amount held in solution by wells and springs in these counties, making their water somewhat "hard" and unfit for washing with soap.

On the site of the Sandy lake dam an excavation about ten feet square, made in the summer of 1893, encountered in the modified drift, at a level a few feet below the river bed, a gravel layer enclosing abundant water-worn and partially rounded lumps of lignite. These masses vary in size from one or two inches to six inches or more in length, and are mostly flattened in parallelism with their bedding planes. It was estimated by Mr. Archibald Johnson, in charge of the construction of the dam, that about two bushels of lignite fragments were thrown out from this small excavation. They are of quality similar to the lignite coal found in thin layers enclosed in Cretaceous shales near Richmond, Ft. Ridgely, and Redwood Falls in Minnesota, and to the thicker Cretaceous lignite beds which are mined on the Souris or Mouse river and west of Bismarck in North Dakota. Small fragments of lignite are found very rarely in the till of all the western two-thirds of Minnesota, including Aitkin county, in which Sandy lake is situated; and gravel layers in wells near Aitkin occasionally contain smoothly rounded pebbles of very compact, nearly black, carbonaceous shale, somewhat resembling graphite. Occurring so plentifully at Sandy lake, this lignite gravel must have been derived from the erosion of some layer of lignite in Cretaceous shales not far distant northward or northeastward.

Only very scanty Cretaceous shale gravel, however, is found in the till and in nearly all the modified drift of this region. The greater part of the Cretaceous beds here may be too soft to yield pebbles, the product of their glacial erosion being principally an indistinguishable part of the fine rock flour or clay in the till. The lignite fragments at Sandy lake are not sufficient, according to the opinion of the writer, to indicate the existence of workable layers of lignite; for they more probably came from thin seams like those known elsewhere in Minnesota, which are mostly about one foot or less in thickness and nowhere exceed three or four feet, being inadequate for profitable mining. Little or no encouragement can be given

to prospecting in this thickly drift-covered region with the hope of finding valuable beds of this brown coal.

IV. GLACIAL DRIFT AND MORAINES.

(Mapped in Plate I, facing page 18, at the begining of this chapter.)

Nearly all of Minnesota is covered by a mantle of drift that averages from 100 to 150 feet in thickness, almost everywhere concealing the bed-rocks, which generally had been subaërially eroded in preglacial times to an approximately flat or only moderately hilly surface. Small knobs and hills of rock which had been spared by the preglacial erosion were doubtless in many places worn down and levelled by the ice-sheet, and its drift was filled into the preglacial valleys, so that the contour of the drift-enveloped country is now more uniform than it was before the Ice age. But on certain belts the drift was left in hills and ridges, accumulated along the margin of the ice where it paused or somewhat reädvanced, apparently because of secular fluctuations of climatic conditions, at successive stages which interrupted its general retreat during the closing part of the Glacial period. Numerous belts extending across areas which have a nearly plane surface of the underlying rocks are thus occupied by drift amassed in prominent hills. Upon the greater part of Minnesota the only hills are formed of this morainic drift, ranging in hight commonly from 25 to 75 or 100 feet, but occasionally attaining much greater altitude, as in the Leaf hills, which rise from 100 to 350 feet above the moderately undulating country on each side. These characters of the bed-rock contour, and of the overlying drift surface, prevail through Cass, Crow Wing, and Aitkin counties, and the region thence north to the international boundary, as also upon most of the area eastward to the sources of the St. Louis, Whiteface, and Cloquet rivers.

Farther northeastward, a region of comparatively scanty drift, with plentiful rock outcrops, begins upon Rainy lake, Net, Pelican, and Vermilion lakes, in the Giant's or Mesabi range (a high granite ridge), and along the bold highland which forms all the northwestern shore of lake Superior. This region, reaching thence northward and eastward into Canada, presents very remarkable contrasts with the other and far greater portion of Minnesota before described; for it has frequent steep rock hills 100 to 200 or 300 feet above the neighboring lakes and streams, and its drift averages probably only from 10 feet or less to 25 or 50 feet in thickness, often giving,

even on the lowlands, ample opportunities for examination of the older geologic formations, and for accurate tracing of their boundaries. Yet this hilly and rocky district is quite surely less uneven than before its glaciation, which in general tended to reduce the hights of the hills and to fill the hollows with drift, or to bar them with drift accumulations whereby most of the very abundant lakes of the district are partially enclosed. In many instances it may be shown here that glacial erosion produced rock basins that are filled by lakes; but more commonly some part of the lake shores consists of drift whose removal would open avenues through which the water could mostly or wholly flow away.

Transportation of Boulders.

The boulders of the drift in northeastern Minnesota have been mostly transported toward the west, southwest, and south, from their parent ledges. In the northwestern part of the state, however, the glacial currents flowed and carried their boulders from the Silurian limestone region of lakes Winnipeg and Manitoba, and from the Archean gneiss and granitic rocks east and north of lake Winnipeg, southward and southeastward into western and southern Minnesota, and thence continued across Iowa to the drift boundary in Missouri and northeastern Kansas. These two fanlike outflows from the farther north and thicker central portions of the ice-sheet were confluent, pushing against and uniting with each other from the northeast and northwest, along a belt which extends southward from near the mouth of Rainy lake and Winnebagoshish and Leech lakes to the vicinity of Brainerd and to Minneapolis, coinciding approximately, for this distance of about 250 miles, with the courses of the Big Fork (or Bow String) and Mississippi rivers.

Throughout the district of this field work and report the drift is mainly derived from the rock formations outcropping and underlying it within distances from a few miles up to fifty miles in the directions whence the glacial outflow advanced. Upon an area of gabbro, or of granite or schists, or slate, or other rock, and for some miles onward, many of the boulders, large and small, and much of the gravel in the till and modified drift, consist of the same kind of rock. The glacially eroded grist comprises frequent boulders up to 5 feet in diameter, usually very few up to 10 feet, and exceedingly rare blocks of larger size, excepting near to prominent and favorably jointed rock outcrops. A much larger proportion of the drift occurs

as small boulders and fragments, gravel, sand, and rock flour, the fine detritus making nearly everywhere the far greater part of the whole mass.

Only where rock formations of restricted area have peculiar characters by which their boulders can be identified with certainty, as distinct from all similar boulders supplied by other formations and districts, is it possible to affirm positively the distance of their transportation. Thus, we find rarely in Big Stone and Otter Tail counties, of western Minnesota, granite boulders with included fragments of hornblende schist,* like much of the granite forming the Giant's or Mesabi range, which was probably their source. These boulders appear to have been carried about 200 miles southwest and west-southwest. A mass of native copper weighing more than thirty pounds, found in Lucas county, southern Iowa,† had been doubtless borne by the currents of the ice-sheet about 600 miles, from the present copper mining region south of lake Superior, or from Isle Royale, first southwestward and then southward through eastern and southern Minnesota, passing west of the Wisconsin driftless area.

The farthest known transportation of rock-fragments in the drift, recorded in part by Dr. Robert Bell, of the Canadian Geological Survey, whose observations are supplemented by my own, is from James bay southwest to North Dakota and Minnesota. The rock thus recognized is a "dark grey, granular, siliceous felsite or greywacke,...... characterized by round spots, from the size of a pea to that of a cricket ball or larger, of a lighter color than the rest of the rock, which weather out into pits of the same form." It occurs *in situ*, as reported by Dr. Bell, on Long island, off Cape Jones, on the east coast of Hudson bay, where it is narrowed to form James bay, having there a southwestward strike, and probably continuing under the sea for some distance in that direction. He notes that the abundance of pebbles and boulders of this rock is the most remarkable feature of the drift on the west coast of James bay and along the Attawapishkat, Albany and Kenogami rivers, and that its fragments have been found by him as far west as Lonely lake, and southward to lake Superior.‡ Farther to the southwest and south I have observed fragments of it, usually

* Final Report, vol. i, p. 626; vol. ii, p. 551.

† C. A. White, Geology of Iowa, 1870, vol. i, p. 96.

‡ Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, vol. ii, for 1886, p. 36G; compare Report of Progress for 1878-79, pp. 22, 230.

only a few inches, but in some instances, a foot or more in diameter, occurring very rarely in the drift in the northeastern part of North Dakota, where the largest piece ever found by me was about thirty miles south of the international boundary and fifty miles west of the Red river, and at numerous localities in Minnesota, where it extends at least as far south as Steele county, seventy-five miles south of St. Paul, and a thousand miles southwest of its outcrop north of James bay.

GLACIAL STRIÆ.

While the most distantly derived boulders of the drift bear testimony of the sum of all the movements of the glacial currents, during the entire Ice age, upon the area across which they came, it is to be remarked that the glacial striæ, or furrows and scratches on the bed rocks engraved by boulders, pebbles, and sand grains frozen in the base of the moving ice-sheet record only the course of the latest glacial current there, excepting such striated rock surfaces as became drift-covered and thus protected from the latest ice abrasion. Probably the average glacial erosion of our rock surface, for different parts of Minnesota, varies from 10 or 20 feet to 50 or 100 feet or more, approaching, but not generally equalling, the depth of the drift. Nearly all of the striæ produced during the early and middle portions of the Glacial period have therefore been erased and their places taken by the later markings. Even where one set of striæ was protected by a drift covering until a considerably divergent set was engraved on adjacent parts of the same ledge, as has been observed at some localities in southwestern Minnesota,* and in many places near Duluth, noted in the following table, it is far more probable that both belong to successive late stages of the glaciation than that any long fraction of the Ice age intervened. When several courses intersect each other on the same rock surface, differing 30°, 60°, or even 90°, in their extremes of deflection, as in numerous instances near Carlton, Thomson and Duluth, these variations seem referable to the closing scene of the glacial retreat when the ice border, irregularly indented in its process of melting and consequently having sudden and great deflections of its marginal currents, was being withdrawn across these striated rock exposures.

Generally outcrops that have been long exposed to the disin-

*Final Report, vol. 1, pp. 505 and 549, with figures 35 and 44.

tegrating action of the weather, having been undoubtedly in many instances bare ever since the departure of the ice-sheet, show few remnants, or only here and there faint traces, of their originally abundant striæ. These long weathered rock surfaces have suffered a slight loss, estimated to vary commonly from a sixteenth of an inch or less to a half inch or sometimes more, worn away, with the delicate glacial striæ, by the rains of many centuries, while yet the planed or rounded forms of the ledges due to their glaciation are unchanged. That so little subaërial erosion has taken place since the end of the Ice age is a sure evidence of the geological brevity of this Postglacial or Recent period, agreeing with the conclusion reached by Prof. N. H. Winchell from his investigations concerning the rate of recession of the Falls of St. Anthony, by which he estimated the length of postglacial time to be about 8,000 years.†

Wherever the ledges have been covered by drift and so protected from weathering, they retain their glacial marks in perfection; and on tracts of plentiful rock outcrops, such striated surfaces are frequently exposed by excavations for streets, cellars, etc., and by the removal of the drift on the borders of quarries. Though most of the striæ of naturally exposed ledges have become effaced, usually a careful search will detect some portions where they remain; and occasionally, even on surfaces evidently exposed during all the Postglacial period, the striation is still very distinct upon spaces 10 to 20 feet or more in extent.

Courses of Glacial Striæ in northeastern Minnesota,
referred to the true or astronomic meridian.

FROM NOTES BY COL. CHARLES WHITTLESEY.*

Vermilion lake............S. 15° W.
Sand Points lake..........S. 55° W.
Namekan lake. also..... S. 55° W.
Rainy lake.......S. W. to S. 75° W.
Big fork of Rainy river at "a fall of six feet over trappose rock," estimated 82 miles by the stream from its mouth ....N. 80° W.

FROM NOTES BY PROF. N. H. WINCHELL, in former annual reports of this survey.

Otter Track lake..............S. W.
Knife lake.................S. 48° W.
Island in Carp lake........S. 40° W.
Sucker lake...................S. W.
Basswood lake, Northeast cape ....S. 15° W.
Ima lake, north shore.......... ....S. 36° W. and S. 23° W.
Island in Thomas lake....S. 25° W.
Sec. 11, T. 64, R. 7 W......S. 30° W.
Delta lake, sec. 28, T. 65, R. 6.. ....S. 25° W.
Sec. 30, T. 63, R. 8..........S. 8° E.
Sec. 35, T. 63, R. 9........S. 12° W.
Sec. 27, T. 63, R. 10.......S. 15° W.
Birch lake..S. 12° W. and S. 22° W.

†Final Report, vol. ii, pp. 314-341, with maps and plates.

* Report of Explorations in the Mineral Regions of Minnesota during the years 1848, 1859, and 1864.

Vermilion lake, twenty localities................S. 17°-24° W., and three other localities.... ....S. 28° W., S. 10° W. and S.
Pike river, tributary to Vermilion lake, two places.......... ....S. 10° and 20° W.
Duluth....................W. S. W.
Prairie river, lower falls, sec. 34, T. 56, R. 25 W............S. 10° E.

FROM NOTES BY MR. HORACE V. WINCHELL, in the Sixteenth and Seventeenth Annual Reports of this Survey.

Little fork of Rainy river, five localities............S. 10°-42° W.
Rainy river, 3½ miles below Ft. Francis................S. 32° W.
Rainy lake, nine localities...... ....S. 32°-64° W.
North fall on outlet from Namekan lake to Rainy lake..S. 30° W.
Bow String river (Big fork of Rainy river), probably in T. 63, R. 26, intersecting striæ. mainly.....S. 10° W. and S. 30° E.
do., a short distance above the last, very distinct glaciation....................S. 60° E. [or, more probably....N. 60° W.]
Deer river, at dam about a half mile above its junction with the Big fork, probably in T. 62, R. 25.......S. 80° E. to due E. ....[or, N. 80° W. to due W.]
Big fork, about three miles above the mouth of Deer river.....................Due E. ....[or more probably, W.]
do., in or near sec. 35, T. 150, R. 25......S. 52° E. [or N. 52° W.]

The cause of the foregoing remarkable deflections will be considered on a following page.

Net lake, in the Bois Fort Indian Reservation....S. 20°-24° W.
Pelican lake, mostly in Ts. 64 and 65, R. 20, four localities ....S. 24°-36° W.
Elbow lake, T. 64, R. 18, two localities..S. 26° W. and S. 28° W.
Trout lake, north of Vermilion lake, two localities.......... ....S. 16° W. and S. 36° W.
Summit of the Giant's range at Hinsdale...............S. 22° W.
Sec. 32, T. 60, R. 13, about..S. S. W.
Sec. 35, T. 61, R. 12, south of Birch lake, about...S. 12°-30° W.
Sec. 10, T. 64, R. 8, south of Ensign lake...............S. 24° W.
Sec. 27, T. 64, R. 8, northeast end of Disappointment lake.. ....S. 34° W.
Sec. 36, T. 62, R. 8, south of lake Isabelle................S. 24° W.
Sec. 15, T. 59, R. 6, southwest of Crooked lake............S. 6° W.

FROM NOTES BY DR. U. S. GRANT, 1892-93.

N. W. ¼ of sec. 27, T. 65, R. 2 W., north shore of lake Louise... ....S. 16° W.
S. E. ¼ of sec. 28, T. 65, R. 2 W., north shore of lake Emma ....S 7° W.
N. W. ¼ of sec. 35, T. 65, R. 2 W., north shore of No-name lake....................S. 2° W.
S. W. ¼, sec. 10, T. 63, R. 3 W., reef in Brulé lake.......S. 18° W.
S. E. ¼, sec. 20. T. 65, R. 4, north shore of a small lake.. ...S. 4° E.
N. W. ¼, sec. 13. T. 64, R. 6. S. 28° W.
N. E. ¼, sec. 3, T. 65, R. 6, on an island..................S. 50° W.
N. E. ¼, sec. 7, T. 65, R. 6, island in Amœba lake.........S. 30° W.
S. W. ¼, sec. 35, T. 66, R. 6, north end of island in lake Avis. S. 30° W.

FROM NOTES BY PROF. G. E. CULVER, 1893.

Pokegama falls, Mississippi river....................S. 50° E.
Prairie river, lower falls. S. 4°-10° E.

On the Bow String river (Big fork of Rainy river):

First rock outcrop observed in descending this stream...S. 5° E., and nearly due E. [more probably W.]
"Another exposure of diorite some five miles down the stream"...S. 70° E. [or N. 70° W.]
Foot of Rice River rapids, on the "upper exposure of greenstone"..................S. 35° E.; and on its second exposure.. ....S. 65° E. [or N. 65° W.]
A few miles below the last.... ....S. 70°-80° E. [or N. 70°-80° W.]
A short distance farther down the river S. 70° E. [or N. 70° W.]
About halfway between the mouths of Rice and Deer rivers ...S. 70°-80° E. [or N. 70°-80° W.]
An eighth of a mile above the Little falls................S. 2° E.
Little falls..............S. 2°-8° E.

Rock gorge of river, ½ mile long, estimated 12 miles below the Little falls.................... ....S. 58°-70° E. [or N. 58°-70° W.]
Big falls.....S. 80° E. [or N. 80° W.]
1½ miles below the mouth of Sturgeon river (which comes in from the west 5 miles below the Big falls) ....S. 24° E.
About 12 miles below the Big falls.S. 58°-62° E. [or N. 58°-62° W.]
About 25 miles below the Big falls, on the lowest rock outcrop observed on the Big fork....................S. 44° W.
Little fork of Rainy river, 4 miles from its mouth...S. 50° W.
Rainy river, 2½ miles below Ft. Francis..................S. 40° W.
do., 1½ miles below Ft. Francis, also......................S. 40° W.
Near the head of Black bay of Rainy lake............. S. 52° W.
West end of Namekan lake. S. 40° W.
Sand Points lake, 10 miles from the mouth of the Vermilion river....................S. 22° W.

FROM NOTES BY MR. W. H. C. SMITH.*

Near Sand Points lake....S. 28 °W.
Knife and Carp lakes..S. 10°-38° W., averaging about........S. 23° W.
Otter Track (Cypress) lake and Cache bay at west end of Saganaga lake.........S. 10°-28° W.; most commonly about..S. 20° W.
Extreme limits of all the observations of glacial striæ on Hunters' Island.......... ... .S. 2° W. and S. 43° W., with average general direction about........ ......S. 20° W.

FROM NOTES BY DR. A. C. LAWSON.†

Rainy lake, east arm (upon the international boundary), from its east-southeast extremity to Brulé Narrows, twenty-four localities.......S. 28°-73° W.
do., East arm, from Brulé Narrows and the Seine river to the mouth of the lake, forty localities.............S. 28°-61° W.
Canadian portions of Rainy lake, with its many bays and several canoe routes northward, 137 other recorded localites....... ....S. 18°-63° W.
Rainy river, island four miles above the Manitou rapids. S. 38° W.
do., one mile below the Long Sault, and at the first and second rapids of Pine river, three localities, alike....S. 24° W.
do., one mile above the mouth of Rapid river...........S. 38° W.

FROM NOTES BY DR. A. C. LAWSON‡ AND DR. G. M. DAWSON.§

Around the Lake of the Woods, observations in about 180 localities by Dr. Lawson and assistants, and in about 60 localities reported by Dr. Dawson, "the great majority", i. e., 82 per cent.........S. 35°-55° W.; but 13 per cent. are..S. 10°-34° W.; and 5 per cent. are...S. 56°-83° W. Only four localities showed courses more westerly than S. 65° W., as follows:
On the southeast side of Big island, striæ bearing....S 75° W. intersect others bearing. S. 37° W.
On the west side of Bigsby island, which, like the preceding, lies near the middle of Sand Hill lake (the southern and largest part of the Lake of the Woods), double sets of striæ were observed in two places, respectively.......... ....N. 80° W. and S. 20° W. and......N. 83° W. and S. 33° W.
On a point projecting from the Minnesota shore in the southwestern part of this Sand Hill lake, striæ bear.......... ....S. 70° W. and 65° W., with others....S. 35° and 33° W.; also....................S. 10° E.

NOTES BY WARREN UPHAM, 1893.

Vermilion lake, west part of Pine island, S. W. ¼, sec. 34, T. 63, R. 16, three places..... ....S. 15°-20° W.
Tower, near the school house, mostly..................S. 10° W. with variation to..S. and S. S. W.
A half mile southwest of Tower ...S. 5° and 15° E., and S. 10° W.
On the south ridge, close to Tower:
At Lee's mine, about.....S. 15° W,
Southeast summit, also about.. ....S. 15° W.

*"Report on the Geology of Hunters' Island and adjacent country," Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, vol. v, for 1890-'91.

†Geol. and Nat. Hist. Survey of Canada, Annual Report, vol. iii, for 1887-'88.

‡Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, vol. i, for 1885.

§Report on the Geology and Resources of the Region in the Vicinity of the Forty-ninth Parallel, from the Lake of the Woods to the Rocky Mountains, 1875.

Southwestern slope of this hill, several places, about 100 feet above Tower.. Due S.-S. 15° W., with rare deflected striæ. S. 10° E.
Greenstone knoll, ½ mile northeast of Tower Junction, beside branch railroad to Soudan, mostly..........S.-S. 5° W.; with other courses..........
S. 15° E., S. 20° W., and S. 35° W.
Soudan, street car depot.......
....................S. 10°-15° W.
do., southwest edge of village
.......................S. 30° W.
North ridge, close to Soudan, ⅛ mile west of summit and 30 feet lower.......S. 20° and 30° W.
also, a few striæ..............S.
do., at west end of the old open mine..............S. 15° W.
Jasper peak, three places near top, each having two sets of striæ........................
..S. 10°-15° W., and S. 30°-35° W.
Ely, many places on top of hill in village, two slightly varying sets (the second most abundant)....................
...S. 20°-25° W., and S. 30°-35° W.
do., ⅛ mile farther east, two courses, both plentiful, intersecting. ....
....S. 15-20° W., and S. 45°-50° W.
Hinsdale, close west of D. & I. R. railroad, several places....
...S. 10°-20° W., and S. 25°-30° W.
do., above the old quarry, several places........S. 15°-20° W.
Nearly one mile northwest of Allen Junction, many striæ in two sets, intersecting.....
..........S. 35° W., and S. 50° W.
Allen Junction, two places, abundant...........S. 45°-50° W.
About two miles southeast from last.................S. 30°-35° W.
Close west of railroad 1 mile south of Little Cloquet river bridge...................S. 35° W.
Rock cut 50 rods long, ¾ mile north of Two Harbors, nine places, mostly.........N. 80° W.; with variations to...........
................W. and N. 70° W.
Top of hill in S. E. ¼ of sec. 27, T. 53, R. 11, 1½ miles west of the last, at hight of about 500 feet above lake Superior.N.75° W.
Lighthouse point, ¼ mile southeast of Two Harbors village, two places..................
...N. 85° W., and (mostly) due W.
Lester Park, at east side of mouth of Lester river, three places, mostly......S. 50°-60° W; also on same rock surfaces...
..S. 70° W., due W., and S. 30° W.

The magnetic needle is deflected here to the N. E. and E. N. E., but these bearings were determined by comparison with the trend of the north coast of lake Superior, and with the direction to elevators in Duluth, 6 to 7 miles distant. All the following observations of glacial striæ in and near Duluth likewise depend not only on compass readings (corrected for average magnetic variation, about 10° east of north), but also on the simultaneously observed courses to prominent buildings or land marks or to the sun. The needle in numerous places varied 10° to 60° or more and occasionally even 180° (pointing to the south instead of north), on account of the influence of the magnetite-bearing gabbro of this area. In many other places, however, the magnetic courses were nearly correct.

In Duluth and its vicinity (with figures in parentheses noting the approximate hights in feet above lake Superior):

East Superior street, east end of rock cut (200), about ½ mile northeast from the Endion school house (which is at 180 feet)....................S. 75° W.
Crest of this cut (250).....S. 70° W.
¼ mile N. E. from Endion school house (225). S. 85° W. and S. 40° E.; both courses being represented by long and deep, clearly glacial furrows on a somewhat weathered rock surface.
20 rods north of this school house, at a hight of nearly 50 feet above it (225)..S. 70° W.,
..S. 85° W., due W., and N. 65° W.
A few feet west of last (225)....
..........S. 80° W. and S. 60° W.
Again, about 5 feet farther west
...........N. 50°, 55°, and 60° W.
50 feet west of last, on a grandly furrowed surface 20 feet long (225)..........S. 75°-85° W.; with broad glacial grooves ½ to ½ inch deep, from which any intersecting finer striæ that may once have existed are lost by weathering.
About 15 rods N. N. W. from the Endion school house (200), in two places, mostly.S.80°-85° W.; also, on the same surfaces....
..................N. 80°-85° W.

On Woodland avenue (490), about ¼ mile south of the Hardy school house (which is at 510 feet) .... W.

Near Buena Vista street (450), ¾ mile east of the great bend of Chester creek ....S. 75° W.

1¼ miles W. S. W. of the Endion school house, near Brewery creek (425), about 30 rods east of Piedmont avenue bridge.. ....S. 85° W.

15 rods west from the last, on ledges in the bed of this brook (425). W., N. 80° W.. and S. 80°-85° W.

About 6 rods S. W. from the last, at a small quarry (460)..N. 85° W.

Extensive smooth ledges ½ mile S. S. E. from the last (425), mostly effaced by weathering N. 85° W., due W., and S. 80° W.

Thence, on continuation of these ledges ½ mile southward (400-325), distinct glacial striæ were seen in many places, occasionally accompanied with large "chatter marks" which are convex eastward, respectively in order from north to south: (1) W.; (2) N. 75° and 65° W.; (3) N. 80° W., crossed by others bearing S. 20° W., which curve within an extent of four feet to a course due S.; (4) S. 50° W.; (5) N. 80° W.; (6) W., S. W., S., and S. E., all clearly glacial and crossing on the same surface; (7) S. 70° W.; (8) N. 80° W., S. 70° W., S. 60° W., S. 50° W. and curving in two feet to S. 30° W.. with others S. 30° W. and curving in six inches to S. 10° W., all on a space of about four feet square, intercrossed; (9) S. 70° W., many parallel striæ, crossed by a few others, N. 80° W.; (10) S. 70° W., S. W. (many), and S. 30° E., the last being surely glacial and extending straight 3 to 4 feet. [This tract is about ¼ to ½ mile N. N. W. of the High School building (which is at 125 feet).]

On the Boulevard near Third and Fourth avenues W. (¼ mile S. W. from the foregoing) and thence southwesterly to the Seventh avenue inclined railway, striæ plentiful in many places (all about 475 feet)............S. 50°-60° W., with occasional deflections to..........S. 75° W. and S. 30° W.

On and near the Boulevard for a half mile southwest from the inclined railway, several places (all about 475 feet), mostly..............S. 50°-60° W., with deflections to........... ..S. 70° W., S. 85° W., and due W.

Above the Boulevard ¼ to ½ mile N. E. from the inclined railway, many places (525-550)... ....S. 70°-80° W.

30 rods W. (555) from the top of this railway (which is at 535 feet)....................S. 65° W.

About 15 rods S. W. (575) from the last..S. 80° W. and N. 80° W.

About 50 rods W. (590) from the top of the inclined railway .. .. S. 80° W.

¼ mile N. W. from this railway (590-600) .... S. 85° W.-W.

½ to ¾ mile N. W. from the railway, three places (about 600 feet), successively............ (1) N. 75°-80° W.; (2) N. 75° W.; (3) N. 85° W.

¾ mile farther N. W., near Highland Park village (675). N. 75° W.

Piedmont avenue, between Seventh and Eighth streets (375), extensive rock exposures, with very distinct glaciation in many places, all... .... S. 65°-70° W.

About ½ mile west of last, close below the Boulevard, on large outcrops (425), striæ remaining in many places........... S. 60°, 65°, 70° and (rarely) 80° W., crossed in one place by striæ S. 20° E., which curve within 18 inches to S. 10° E.

It is noteworthy that such curving striæ, seen elsewhere in twenty places or more, are in all cases deflected to more southward courses, when traced forward as the ice currents moved. At this locality the curving marks are rather broad and deep gouges, far more so than any of the prevailing W. S. W. striæ.

Fifth avenue W. (at hight of about 300 feet), 20 rods west of the Institute of the Sacred Heart, mostly......S. 55°-65° W.; crossed by a few deep glacial furrows ....S. 25° W.

Lake shore, 10 to 15 rods N. E. from mouth of Chester creek, striæ most abundant...S. 50° W.; also common, S. 60° W.; with a few deflections to.......... .... S. 30° W. and S. 70° W.

Lake shore, about 30 rods S. W. from Chester creek .... S. 40° W., S. 55° W. and S. 70° W.

Superior street ⅛ mile N. E. from the city hall and public library (40), several places, mostly ....S. 60° W.
with others................. ..... S. 45° W., and S. 70°-80° W.
Michigan street, near Twelfth avenue W. (50)..........S. 45° W.
do., between Fourteenth and Fifteenth avenues (25)....... .... S. 55°-60° W.
do., within ⅛ mile S. W. from the last (at hight of 20-30 feet) to Garfield avenue (which leads over Rice's point to West Superior), mostly.S. 40° W. but intersected by........... ....S. 65° W. and due W.

In West Duluth.

At quarry about ⅛ mile N. E. from the Longfellow school house (75)...............S. 70° W.
10 rods W. of last (100)......... .... S. 65°-70° W.
About 15 rods farther W. N. W. (100) ....S. 68° W.
⅛ mile north of the foregoing, on the D., M. & N. railway near Fourth avenue W. (175) ....S. 75°-80° W.
15 rods E. of last, at the intersection of this railway and State street (175)...N. 80°-85° W.

In Carlton and its vicinity.

Thomson, 15-20 rods S. E. of the depot..............N. 80° W.
3 to 6 rods east of the last..... ....N. 52°-55° W.
About 10 rods west of the Thomson dam.........N. 70° W.
Beside the St. P. & D. railroad ⅛ mile west of St. Louis river, mostly.................N. 70° W. intersected by............... .....N. 55°-60° W. and N. 80° W.
About 15 rods west of the last, mostly ....N. 80° W.; with others, equally distinct, crossing on the same surface ..S. 60° W., S. 35° W., S. 10° W., S. 20° E. and S. 30° E.
Northeast edge of Carlton village, on street leading to Thomson .... N. 80° W.

The very prominent and plentiful slate outcrops at and near Carlton, and northward to Cloquet, have almost completely lost their glacial marks by weathering. In searching several hours, both at Carlton and Cloquet, I was unable to find any striæ surely referable to glaciation.

Close north of the N. P. railroad about 1 mile west of Carlton, a few glacial striæ.. .... S. 50°, 55° and 65° W.

Within 1¼ miles southeastward from Carlton the N. P. railroad has five rock cuts, at four of which I searched in vain for glacial marks. The fifth cut, however, about 30 rods long and 15 feet deep, 1¼ miles from Carlton, shows on the recently uncovered slate of its edges at each side of the railroad very interesting glacial striæ, as follows:

On the southwest side, near the northwest end of the cut..... ....N. 65° W., and N. 45° W.
Two rods S. E. from the last, plentiful striæ.........N. 45° W.
Again, two rods farther S. E., abundant...............S. 80° W. intersected by ....S. 15° W., due S., and S. 45° E., each of these courses being represented by only two or three glacial gouges.
About three rods farther S. E., many very clear striæ.....due W.
25 feet onward S. E...S. 85° W., and partly S. 80° W. and due W.

The same westward striation is also well shown on this southwest side of the cut in other places within two rods southeastward.

On the northeast side, at the crest of the cut, about 10 rods S. E. from the last, plentiful ....N. 80° W.; crossed by short glacial gouges ....S., S. 20° E., and S. 45° E. These cross markings are two to six inches long, numerous.
About 25 feet N. W. from the last, the well preserved main striation is.........W.-S. 85° W; crossed by a few short glacial marks.....S. 20° E., and S. 45° E.

Deflections of Glacial Currents.

During the time of maximum extent and thickness of the ice-sheet, its currents doubtless flowed southward upon all the northern part of Minnesota, but with considerable variation on one side to the west and on the other to the east of due south. In the region bordering lake Superior, and thence south and southwest to the Mississippi, the currents were turned southwesterly, for the driftless area of Wisconsin, whose margin extends also into southeastern Minnesota, indicates that the glacial outflow from the western part of the lake Superior basin moved in a curving course successively to the southwest, south, and east of south, in its passage through Minnesota. Uniting with this flow the more western part of the ice-sheet above the Manitoba lake region and the Red river valley moved nearly due south as the axial portion of the great ice-lobe which stretched across Minnesota and Iowa, becoming at the culmination of the Glacial period confluent south of the driftless area with the ice that moved southwestward from the region of lakes Michigan, Huron, and Erie. During the departure of the ice-sheet, however, when its latest currents were recorded by the striæ which remain for our inspection, the inequalities in the rates of melting of different portions of the retreating ice border shaped it often into minor lobes and deep embayments, very unlike its outlines at the time of greatest extent, and continually changing in form as the process of the melting and recession pushed the ice boundary back. In general this retreat was from south to north, but the courses of the moraine belts show that on some tracts it was from west to east, and less frequently, at least in this state, from east to west. Everywhere the outermost few miles of the vanishing ice-sheet had its currents turned strongly toward its boundary, since on that side there was a steep slope of the ice surface.

In the vicinity of Duluth, where the foregoing notes show an unsurpassed complexity of divergent and intersecting glacial striæ, we may generally refer the courses between S. 30° W. and S. 60° W., inclusive, to the main current of the ice-sheet here previous to any great deflections by the irregularities of the final melting. Occasionally, however, local southward deflections were doubtless of much later date, being due to indentations of perhaps only a few rods extent in the retreating ice border. The more common directions, ranging from S. 70° W. to W. and N. 80°-70° W., belong to the time of glacial recession

and imply that the withdrawal of the ice boundary here was from west to east.

Similar westward deflections of the glacial currents crossing the shores and islands of the Lake of the Woods and on the Big fork of Rainy river are likewise referable to the closing stages of the glaciation. When the ice was thickest and during its retreat nearly to this region, the currents of ice flow from the area of Paleozoic limestones west of the Lake of the Woods and lake Winnipeg passed south and southeast, carrying their limestone drift to the mouth of Rainy lake and the basin of the Big fork, becoming there or close eastward confluent with the ice flow from the north and northeast, which overspread all of the country north of lake Superior. But during the recession of the ice the laving action of lake Agassiz appears to have caused exceptionally rapid melting along the Red river valley and upon the whole area covered by this glacial lake east to the Big fork, so that the ice currents there were shifted from southeastward to westward and even northwestward courses, being turned toward the open and lower lake expanse. In a former report,* I supposed these striæ on the Big fork to represent an increasing eastward deflection of the previous southeasterly current; but it now seems to me more reasonable, from consideration of the courses of moraines and of the extent of lake Agassiz in northern Minnesota, to attribute their deflection to the somewhat earlier melting of the ice from the part of the lake Agassiz area crossed by the Rainy river than from the upper part of the Big fork basin, whereby the latest ice currents on the Deer river and contiguous parts of the Big fork were almost reversed from their former direction.

The changes in the directions of the ice-flow near Duluth were more remarkable in their abundant evidence by glacial striæ than I have anywhere else found; but observations comparable with these were recorded on the quartzyte ridge in Cottonwood county, southwestern Minnesota,† and I have seen almost equally interesting and plentiful deflected glacial striæ in Somerville, Mass.‡ It is also to be noted that the overlapping of northeastern drift by northwestern drift in Wright county, Minnesota, and thence eastward to the St. Croix river

*Geol. and Nat. Hist. Surv. of Canada, Annual Report, new series, vol. iv, for 1888-89, pp. 119, 120 E.

†Geology of Minnesota (Final Report), vol. i, pp. 503-505.

‡Proc., Boston Society of Natural History, vol. xxvi, pp. 33-42, March 15, 1893.

on the boundary of Wisconsin,§ proves for that large district during the closing stages of the Glacial period a reversal of the direction of glacial currents far more extended in space and time and more important in their deposition of drift than in the Big fork district.

TILL.

Unstratified glacial drift, called till, or boulder-clay, which was laid down directly by the ice-sheet without modification by water transportation, assorting, and deposition in beds, occupies probably two-thirds, or a larger part, of northeastern Minnesota. It consists of boulders, gravel, sand and clay, mingled indiscriminately together in a very hard and compact formation, which therefore is frequently called "hardpan." In this part of the state, the boulders of the till are usually so plentiful that they are sprinkled somewhat numerously on its surface; yet there are seldom more, on the large portions of the country which are adapted for agriculture, than the farmer needs to use, after clearing them from his fields, for the foundations of buildings and for walling up his cellar and well. They are rarely abundant enough to make walls for the enclosure of the fields, as in New England.

Three kinds of till occur in this region, each being mainly restricted to its distinct geographic limits; but on the belts containing their general boundaries, there is often an overlapping of one on another, or successive alternations of two interbedded. Adjoining portions of the ice-sheet have won and lost once or repeatedly in pushing against each other.

1. On the west, the till brought by the southward and southeastward glacial currents contains plentiful boulders, not only of Archean and Taconic rocks, but also of the Paleozoic magnesian limestones which are the bed-rocks of a large part of Manitoba.

2. Over the greater part of the country eastward from the Big fork, and from Winnebagoshish and Leech lakes, the till was derived from the north and northeast and contains still more plentiful Archean and Taconic boulders, as granites, gneiss, schists, gabbro, quartzyte, slate, etc., while boulders of limestone are exceedingly rare or altogether absent, their only source being Paleozoic formations in the basin of James and Hudson bays.

§Proc., Am. Assoc. for Adv. of Science, vol. xxxii, for 1883, pp. 231-234. Geology of Minnesota, vol. ii, pp. 254-256, 409-413.

3. The third kind of till is that which was brought by the ice-flow from the lake Superior basin. It is characterized by comparative scantiness in the supply of granite, gneiss, crystalline schist and gabbro boulders, by the absence of limestone, and by the large proportion of fine detritus of dull reddish color from the erosion of the Cambrian red sandstones and shales, and of the partly sedimentary and partly igneous Keweenawan series, which form the shores and bed of lake Superior. This red till, with few boulders, has its typical development about Duluth and Superior, and forms the flat expanse which gradually rises from the west end of lake Superior along the Nemadji river and the lower part of the St. Louis river. Thence, with slow decrease of the prevailing deep redness of its color, it extends northward to Biwabik, westward into the southeastern part of Aitkin county, and southward to St. Paul and Minneapolis, though on a large region from southern Pine county nearly to St. Paul, it is covered, as was before noticed, by overlapping northwestern till.

Along the Duluth & Iron Range railroad from Highland station to the St. Louis river, and in the excavations for working the Biwabik iron mine, I observed many very interesting sections of alternating and often interbedded till deposits of the second and third kinds here described, derived respectively from the north or northeast and from the basin of lake Superior on the east. Plate II shows four of these sections. Though found abundantly in this belt, such alternating till accumulations, attributable to changes of glacial currents, are very rare in most drift-bearing regions. They here belong probably to the time of the final recession of the ice-sheet, when, as we have seen by the deflected courses of striation, its currents were far more liable to changes than during the previous time of greater extent and depth, and resulting generally steady flow, of the ice. These alternations of till deposition seem to me well accordant with the view which I have elsewhere presented,* that the drift during its transportation was englacial, and that its deposition, excepting on a broad marginal portion of the drift sheet, was chiefly reserved until the time of glacial recession. Much of the previously englacial drift appears then to have become amassed beneath the ice as a ground moraine of subglacial till. Probably in these sections no more than 1 to 3 feet, or at the most 5 to 10 feet, in the latter case comprising the two upper

*Bulletin, Geol. Soc. of America, vol. v, pp. 71-84, Jan. 1894.

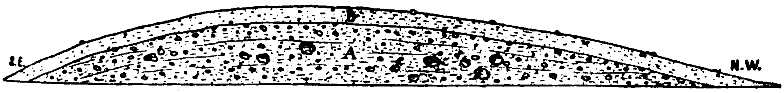


FIG. 1. SECTION ON THE DULUTH & IRON RANGE RAILROAD, IN THE NORTH PART OF SEC. 1. T. 54, R. 12, THREE MILES NORTHWEST OF HIGHLAND STATION. *Length, ¼ mile; hight, 25 feet.*

FIG. 2. SECTION ON THE DULUTH & IRON RANGE RAILROAD. IN THE SOUTH PART OF THE S. W. ¼ OF SEC. 23, T. 55, R. 12, ½ TO ¾ MILE NORTH OF THOMAS SIDING. *Length, ¼ mile; hight, 6-15 feet.*

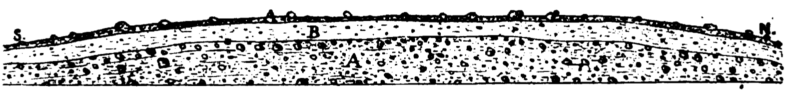


FIG. 3. SECTION ON THE DULUTH & IRON RANGE RAILROAD, IN THE SOUTHEASTERN PART OF SEC. 15. T. 55. R. 12, TWO AND ONE-HALF MILES SOUTHEAST OF CLOQUET RIVER STATION. *Length, ¼ mile; hight, 20 feet.*

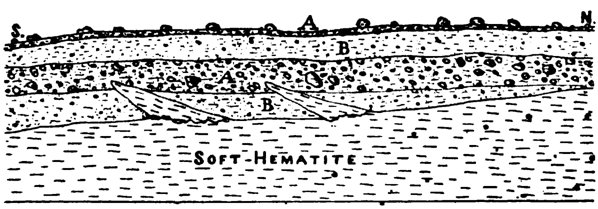


FIG. 4. SECTION OF PART OF THE WEST SIDE OF THE BIWABIK IRON MINE, OCT. 18, 1893; SHOWING IN THE BASAL PART OF THE DRIFT TWO LARGE MASSES OF THE RED IRON ORE WHICH WERE GLACIALLY UPLIFTED AND PROBABLY TRANSPORTED VERY SHORT DISTANCES. *Length of section, 150 feet; hight of drift above the ore deposit, 15 to 25 feet.*

A. Till of yellowish gray color, but bluish at considerable depths, containing plentiful and often very abundant boulders, derived from the north and northeast.

B. Till of somewhat reddish gray color, containing few or often rare boulders, derived from the east.

layers of the till, can have remained as englacial and finally superglacial drift when the ice boundary was withdrawn across this area.

RETREATAL MORAINES.

Northeastern Minnesota is crossed by several belts of knolly and hilly till, with far more abundant boulders than are found on its more extensive comparatively smooth tracts. These belts of somewhat thicker, more rocky, and prevailingly ridged drift were accumulated along the border of the ice-sheet during stages of halt or slight reädvance interrupting its general retreat at the close of the Glacial period. Wherever the vicissitudes of the wavering climate caused the chiefly waning border to remain nearly stationary during several years the outflow of the ice to its melting steep frontal slope brought much drift which had been englacial and on account of the ablation had largely become superglacial, being exposed on the surface of the departing ice-sheet. As these marginal accumulations of drift record the position of the terminal line of the ice-sheet when they were formed, the name terminal moraines has been usually applied to them, but they also may be called, perhaps more properly, retreatal or recessional moraines.

Four moraine belts have been traced in the part of Minnesota northwest of lake Superior, and another, lying next south and formed before any considerable part of the area of this lake was uncovered from the ice-sheet, is also included in the following descriptions. In their order from south to north, these are the Fergus Falls, Leaf Hills, Itasca, Mesabi, and Vermilion moraines, being the eighth to the twelfth and most northern in the series of moraines whose courses have been mapped in this state. A map showing these moraines, the directions of glacial striæ, the areal distribution of the glacial and modified drift, and the extent of the glacial lake Agassiz in northern Minnesota, forms Plate I, facing page 18, at the beginning of this chapter.*

Fergus Falls Moraine.

A belt of morainic drift, chiefly till with many boulders, amassed in hills and irregular ridges 50 to 100 feet above the

*On a smaller scale, the courses of the moraines and other features of the glacial geology of the entire state of Minnesota are mapped in Wright's "Ice Age in North America," 1889, p. 546. They are shown in detail for the southern half of the State by the maps in volumes I and II of the Final Report of this Survey. Many details of their mapping and correlation throughout the northern half of Minnesota remain yet to be supplied.

intervening hollows and frequent lakelets, enters Aitkin county at the northwest side of Mille Lacs. Thence it extends with a width of five to ten miles northward to Cedar lake and to the lakes surrounding Deerwood in Crow Wing county, having in this part an unusual expansion and probably marking a northwestwardly re-entrant angle of the ice-border. Passing from Farm Island and Cedar lakes eastward, the moraine has a width of about five miles. In the southern part of this hilly belt lie Hanging Kettle, Diamond, and Mud lakes, the northern part of Elm Island lake, and Cranberry, Rabbit, Long and Dam lakes. At the northeast corner of Kimberly township the moraine has a fine development in many bouldery hills upon a width of two or three miles next northwest and north of Portage lake, being there crossed by the Northern Pacific railroad.

If my correlation is correct, the vicinity of Portage lake belongs to a second re-entrant angle, with its apex pointing northeastward, from which the moraine, mostly less conspicuous, turns back and passes by the east side of Dam lake, forms high hills south of Sugar lake, and thence approximately coincides with the eastern watershed of Mille Lacs, until in the southern edge of Aitkin county it curves around to an east and northeast course, passing into Pine county as the hilly belt enclosing the Pine lakes. The series of low drift hills thus traced is provisionally regarded, in the descriptions of its portions in Crow Wing and Pine counties*, as the continuation of the Fergus Falls moraine, which is the eighth of the moraines recognized and mapped in their geographic and chronologic succession, crossing the southern and western part of Minnesota.

In northwestern Pine county this moraine is well developed from the Pine lakes northeast to the Kettle river; and farther northeastward I believe that it is represented by a belt of somewhat hilly drift extending along the east side of the Moose Horn river in southern Carlton county, through T. 46, R. 19, and into Mahtowa (T. 47, R. 18); but thence probably it turns back from a re-entrant angle of the ice front and runs southward through T. 46, R. 18, and eastward past Oak and Net lakes in the north edge of Pine county, to cross the state line nearly on the watershed between the Nemadji and St. Croix basins. A tract of moderately hilly till which I observed one to three miles east of Barnum, and its extension southward by Bear, Hanging Horns, Moose Horn, Long, and Moose lakes, belong

*Final Report. vol. ii, pp. 605, 642.

to this looped morainic belt; and another portion, consisting partially of till with a somewhat rolling surface, but in larger part of low kame-like accumulations of sand and gravel, is crossed by the Great Northern railway in its first three miles southwest of Holyoke.

Such correlation of these morainic tracts seems to be harmonious with the course of the outer moraines in northwestern Wisconsin west and north of the driftless area, as mapped by Chamberlin.† It also accords well with the directions of glacial striæ found very abundant and distinct on the plentiful rock outcrops in the vicinity of Carlton, Thomson, Duluth, and Two Harbors, which, as before noted, run prevailingly west-southwestward, but in very many places also display wide deflections to the southwest and south and to the west and even north-northwest. The divergent and variable glacial currents by which these striæ were made doubtless belonged mostly to the time of recession of the ice border across that district. We thus learn that the rapidly wasting ice in its departure from the western end of the lake Superior basin had a definitely lobate front similar to the looped course assigned to this moraine in Aitkin, Carlton, and Pine counties. Between the times of formation of the eighth and ninth or Fergus Falls and Leaf Hills moraines, as these names are here used, the area of these extraordinary divergent and often intersecting striæ was uncovered by the glacial retreat.

Leaf Hills Moraine.

The next halt or readvance of the chiefly receding ice-border was at the belt of prevailingly knolly and ridged and in part prominently hilly drift, with many boulders, which extends from the west side of Gull lake, in southern Cass county, northeastward past White Fish lake in northwestern Crow Wing county, and north of lake Washburn in eastern Cass county, to Hill or Poquodenaw lake and "mountain" (an especially prominent morainic hill which rises about 250 feet above the surrounding country), in northwestern Aitkin county. This belt is probably the representative of the ninth or Leaf Hills moraine, which in Otter Tail county is partially united with the Fergus Falls moraine, the two together making the conspicuous Leaf hills (or "mountains," as they are commonly called), 100 to 350 feet high. Beyond Poquodenaw the moraine has a low and inconspicuous development east-northeasterly to the

†U. S. Geol. Survey, Third An. Rep., for 1881-82, Plates xxviii and xxxv.

—4

Mississippi river; but near the east bank of the river, about a mile north of Aitkin county, it again forms a high hill, known to lumbermen and log-drivers as the "Grub Pile," in the southeast part of sec. 25, T. 53, R. 24, rising about 200 feet above the river.

From this hill as the apex of a re-entrant angle of the ice-sheet, the moraine turns back and extends nearly twenty miles southward to Sandy lake. Along the first six miles of this course it is mainly covered by level or only moderately undulating stratified drift, but in the south edge of T. 52, R. 23, it rises very prominently in Bald bluff, close east of the Mississippi, and in a series of irregular hills continuing thence eastward through the south part of secs. 33 and 34 of this township and the north edge of secs. 4 and 3, T. 51, R. 23. The crests of these hills are 150 to 200 feet or more above the Mississippi, and afford a wide view, the Poquodenaw hill being visible about fifteen miles distant on the west, and the hills of the tenth or Itasca moraine, bordering Pokegama lake, twenty miles away at the northwest. Moraine hills 75 to 150 feet high stretch from Bald bluff southward along the east side of the Mississippi to Sandy lake. Thence this belt, lower and less distinct, consisting partly of kame-like deposits of modified drift and partly of till, curving southeastward, makes the shores and islands of Sandy lake and bounds the northeastern arm of Rice lake, beyond which it passes eastward by Round and Big Island lakes and through T. 49, R. 22, where its low swells, hillocks, and ridges project only 20 to 40 feet above the many tamarack swamps.

Eastward from Aitkin county this moraine is narrowly and scantily developed in the northwest corner of Carlton county, but becomes more prominent and broader in the vicinity of Prairie lake, beyond which, as I am informed by Mr. J. E. Spurr, its hills and ridges occupy a width of five to six miles along the south side of the St. Louis river to Stony Brook and Nagonab. Curving northward beyond the St. Louis, it borders both sides of the Cloquet river for several miles, passing northwest of Grand lake. The same belt probably continues east-northeast to a morainic tract, observed by Mr. A D. Meeds, adjoining the Cloquet river and Island and Boulder lakes in the southern third of T. 53, R. 14, and to the narrow but typically hilly moraine which is crossed by the Duluth & Iron Range railroad a mile north of Highland station. It is supposed to reach the north shore of lake Superior about mid-

way between Duluth and Pigeon point. Its course beyond Highland station, however, has been definitely ascertained for only about thirty miles. Along this extent, passing east-northeast to the middle of the east side of T. 57, R. 8, the moraine has been mapped by Mr. Arthur H. Elftman in his exploration for this Survey during the summer and autumn of 1893, who reports it admirably represented by a belt of very irregular drift hills from a half mile to two miles wide, with summits 50 to 75 feet above the land on each side.

Itasca Moraine.

Extending eastward from lake Itasca, this tenth moraine attains a grand development along the south side of Leech lake, being there about ten miles wide. In the southern half of its width it encloses Ten Mile and Fourteen Mile lakes, and Woman, Wabado and Little Boy lakes. Thence it continues east-northeasterly across Itasca county, where its abundant knolls and hillocks of drift, as described by Prof. G. E. Culver in another part of this report, lie on the northern slope of a high Cretaceous ridge in T. 54, R. 26, cover much of the lower country bordering the shores of Pokegama lake within the next ten miles, occupy considerable tracts a few miles north and east of Grand Rapids (attaining a maximum altitude of 300 feet), and reach from near the falls of the Prairie river east-northeast past the Diamond iron mine and along the watershed between the Prairie and Swan rivers to Hibbing.

Along the next thirty miles, to the Embarras lakes, Mr. Spurr's descriptions and mapping indicate that the Itasca and Mesabi moraines are united in a belt mostly two to three miles wide, which coincides closely with the granite ridge known as the Mesabi or Giant's range. East of the gap in this range through which the Embarras river flows (expanding along the greater part of its valley in a series of beautiful lakes), both these moraines veer to the south of the granite ridge. On the Duluth & Iron Range railroad the exceedingly knolly and confusedly ridged but low belt of the Itasca moraine, strewn with a countless profusion of boulders of all sizes up to ten feet in diameter, is crossed from about a half mile to two and a half miles northwest of St. Louis River station. For observation of the rough contour and abundant boulders which are usually the two chief characteristics of these retreatal moraines, I know of no other more impressive view than is seen here from the passing train, although none of the elevations rise more than 50 or

75 feet above the adjoining tamarack swamps and the plentiful bowl-like hollows which are enclosed by the morainic accumulations.

In Lake county the moraine varies from one to two or three miles in width, and crosses ranges XI to VIII (the belt of Mr. Elftman's exploration in 1893) along the line dividing Ts. 59 and 60. His descriptions show that the moraine along this extent of twenty-four miles is typically developed in very irregular low hills and ridges, mostly between 50 and 75 feet in hight. Eight to ten miles farther on, taking an east-northeast course, its hills of drift, heavily covered with white pine, are reported by Mr. H. V. Winchell as surrounding lake Harriet, at the head of the Isabelle river, with ridges of very abundant boulders close northward. Its course thence eastward to the coast of lake Superior, which it may reach in the vicinity of Grand Marais or near the mouth of Brulé river, has not been traced.

Mesabi Moraine.

The most northwestern of the morainic tracts in Minnesota which are here correlated together as the Mesabi or eleventh moraine lies between the south and north divisions of Red lake and consists of a high till ridge, with many boulders, some two miles wide and extending about ten miles east from the Narrows, with a continuous altitude 150 to 200 feet above the lake. Forty to fifty miles southeast from this tract, lower drift hills, referred to the same moraine, border the north side of lake Winnebagoshish, and reach thence southeastward to Deer and Bass lakes, near which they occasionally rise to hights of about 200 feet above the general level. Along a distance of twenty miles to the north from the last named lakes, Prof. Culver reports irregular groups and short series of drift hills, mostly less than 100 feet high, which seem to represent the complex accumulations of a re-entrant angle of the ice-border. From Spider, Trout and Wabano lakes, this moraine passes eastward, and appears to be merged with the Itasca moraine to form a compound hilly belt along the Mesabi range from close north of Hibbing to the upper Embarras lake northeast of Biwabik. At Mesaba station on the Duluth & Iron Range railroad, and within a mile southeastward, this Mesabi moraine comprises many hillocks and short ridges 20 to 40 or 50 feet high. Thence continuing northeast, it is represented by characteristic knolly and hilly drift deposits and abundant boulders on the south side of the western part of Birch lake, and through the northern

part of Ts. 60 in Rs, XI to VIII, where it is mapped by Mr. Elftman, lying two to five miles north of the Itasca moraine, and occupying a width of one to two miles. It probably comes down to the lake Superior shore about 70 miles farther east, in the Pigeon River Indian reservation, passing thence beneath the lake level.

Vermilion Moraine.

A twelfth moraine, named from Vermilion lake, along whose southern side it is well exhibited, as also south of Pelican and Net lakes, was first carefully studied and mapped during my field work in 1893. The portion of its course which I have examined reaches about 40 miles, from the west extremity of Vermilion lake east-southeast to Tower and thence east-northeast to Ely. In total, its whole extent yet known is nearly 75 miles, beginning at the west on the south side of Net lake, where Mr. C. L. Chase, engaged during the past summer in government township surveys, reports a belt of irregularly grouped drift hills, 50 to 100 feet high, with very abundant boulders. Next south of Pelican lake it occupies a width of one to two miles, and it averages about one mile wide in its course skirting the southern shores of Vermilion lake for the distance of twenty miles from its west end to Tower. This belt in most portions is distinguished more by its wonderful profusion of boulders, ranging in size up to 5 or 6 feet and occasionally 10 or 15 feet in diameter, than by its large amount of drift amassed in hillocks and ridges. Its multitudes of boulders strow the surface of the Tower town site, and are conspicuously piled upon the southern slope of the high rock hill called the South ridge, just north of this town; but they are absent from the top of this ridge and from its northern slope, which are chiefly bare rock. Turning northeasterly for the next one and a half miles, this moraine thinly caps the North ridge at Soudan, above its iron mines. Thence it runs to the east and skirts the northern and eastern base of Jasper peak, which, like the top of the ridge near Tower, has almost no drift.

Six to ten miles farther east, this belt is crossed by the Duluth & Iron Range railroad, on which its bouldery drift knolls and ridges are cut through in many places within two miles west and an equal distance east of Robinson Lake station. At Ely its boulders are very abundant in and near the village. Less than a mile to the south, associated with the morainic belt, is an irregular esker ridge of sand and gravel, often very coarse,

trending from west to east and here and there expanding into small plateaus, with altitudes mostly 50 to 75 feet above the railroad and iron mines. Four to seven miles east of Ely, plentiful low drift hills, with many boulders, were observed by Mr. Elftman adjoining the north end of White Iron lake, southeast of Garden or Eve lake, and north of Farm lake. The extent of this belt beyond its limits as here described remains unexplored; but it is doubtless traceable west at least to the area of lake Agassiz, and much farther eastward.

Although this morainic belt is very distinct and certainly records a nearly stationary stage interrupting the retreat of the ice-sheet, I estimate its volume of drift added above the average of the surrounding region to be only 5 to 10 feet on its variable width of a half mile to two miles. A half, or at least a third, of this added volume consists of boulders from six inches to ten feet in diameter.

For the region of Ely and Vermilion lake I estimated the volume of all the drift thus: bare ledges of rock, with no drift or too little to be worth consideration, about a tenth of all the surface; ledges thinly drift covered, probably four-tenths, with an average of about 5 feet of drift; while the remaining half of the country, having diverse deposits of sand and gravel, retreatal moraines, or smoother tracts of till, may have an average depth of 40 feet of drift. By this estimate the mean thickness of the drift there, if uniformly spread, would be about 22 feet.

V.—MODIFIED DRIFT.

The deposits included under this title are waterworn and stratified gravel, sand and clay or silt, which were washed away from the drift upon and beneath the retreating ice-sheet by the streams due to its melting and to accompanying rains. Kames, eskers, sand and gravel plateaus and plains, the valley drift (varying from very coarse gravel to very fine loess and clay, often eroded so that its remnants form terraces), are the principal phases of the modified drift. In being derived directly from the ice-sheet, these deposits had the same origin as the glacial drift forming the common till and the greater part of the retreatal moraines; but they were modified, being separated from the coarser portions, further pulverized or rounded, and assorted in layers, by water.

Kames and Eskers.

Associated with the till in the moraines, a considerable part of these accumulations of marginal drift often consists of irregularly stratified gravel and sand in knolls and short, irregular ridges, which are called kames. Such stratified deposits are also occasionally found on the general till expanse between the morainic belts. In both situations they are attributable to deposition by small streams descending from the melting surface of the ice-sheet, being accumulated in the short cañon-like gorges which were melted into the ice-border at their mouths. The slackening of the steep and rapid descent of the streams there emerging upon the land in front of the ice caused them to deposit the coarser part of their load of gravel, sand, and clay, which was left in these hillocks and ridges when the enclosing ice-walls melted away.

Plateaus of gravel and sand, deposited similarly as kames but filling broader indentations of the retreating ice-front, have a considerable development in the vicinity of Sandy lake, with altitudes 50 to 75 feet above the lake level. They also occur west of Carlton and close southeast of Cloquet, and in numerous other localities. Within one to two miles south of White Iron lake, they are described by Mr. Elftman as forming flat-topped hills about 100 feet high.

Eskers, which are also the deposits of glacial streams but differ from kames in forming prolonged, narrow ridges, a half mile to one mile or sometimes several or many miles in extent, are infrequent in this state. Only a few examples have been noted in the large northeastern region which is here reported, and none has been traced along a distance of more than one or two miles.

Valley Drift and Plains.

Moderately undulating or nearly level tracts of sand and gravel, spread on the land in front of the retreating ice-sheet by streams which had gathered this modified drift from the melting ice surface, are found extensively developed in Wadena, Hubbard, Cass, Crow Wing, and St. Louis counties, and to less degree in many other portions of northeastern Minnesota. Areas reaching ten to twenty miles on each side of the Crow Wing, Pine, and St. Louis rivers, consist of these plains, often bearing chiefly jack pine (Pinus banksiana), but in their more rolling and ridgy portions also commonly bearing the red or Norway pine. Where these lands are very moist, lying only a few feet above the stream courses, and especially, as in parts

of the St. Louis basin described by Mr. Spurr, where thin deposits of till are spread like a veneer above the modified drift, the larger and more valuable white pine grows. The soil preferred by this tree, however, is the till or boulder-clay, which generally rises higher than these areas of modified drift and bears a heavy growth of hardwood (species of poplar, birch, oak, elm, ash, maple, basswood, and other deciduous trees), interspersed with white pine, sometimes only seen here and there as scattered trees, but frequently occurring in small or large groves, from a few rods to several miles in extent.

VI. THE WESTERN SUPERIOR GLACIAL LAKE. AND THE LATER GLACIAL LAKES WARREN AND ALGONQUIN.

If the courses of the Fergus Falls and Leaf Hills moraines are rightly traced as noted in the foregoing pages, the earliest outlet from the Western Superior glacial lake, held by the barrier of the waning ice-sheet still occupying the central and eastern part of that lake basin, probably flowed across the divide between the head streams of the Bois Brulé and St. Croix rivers, where a remarkable eroded channel is found.* The indentation of the ice-front north of the Wisconsin driftless area at the time of formation of the first or Altamont moraine points decisively to the melting backward of a great re-entrant angle in the ice boundary upon the country between Duluth and Ashland, including the place of the Bois Brulé-St. Croix outlet, at a time previous to the melting of the ice upon the district reaching west from that outlet to Aitkin county. The correlations of retreatal moraines given here and in the second volume of the Final Report imply the probable beginning of existence of the Western Superior ice-dammed lake between the times of formation of the seventh and eighth or Dovre and Fergus Falls moraines. But after the accumulation of the latter and before the time of the next or Leaf Hills moraine, the ice-melting in the western portion of the lake Superior basin and thence west to the Mississippi river was very rapid, so that the greater part of Aitkin county, the whole of Carlton county, and the country from Duluth north to Grand, Wild Rice, and Island lakes, and from Two Harbors north to Highland station, were uncovered from the departing ice-sheet. According to the probable duration of the glacial lake Agassiz, estimated to have been only about 1,000 years†, in which the stage between

*Geology of Minnesota. Final Report, vol. ii, pp. 642, 643.

†Geol. and Nat. Hist. Survey of Canada, An. Rep., new series, vol. iv, for 1888-'89, pp. 50, 51 E.

the Fergus Falls and Leaf Hills moraines was a small fraction, this retreat of the ice from Aitkin and Carlton counties and the west end of lake Superior appears to have occupied no more than a century or perhaps only half a century.

The old channel of outflow to the St. Croix river has a width of about a fifth of a mile in its narrowest place. Its bed is 1,070 feet above the sea, or 468 feet above lake Superior; and it is bordered by bluffs about 75 feet high, showing that when the course of outflow began here the Western Superior glacial lake was about 550 feet above the present lake level. Probably the highest part of the swamp now forming the watershed in the channel has been filled twenty to twenty-five feet since the lake forsook this mouth, which was thus lowered by erosion some 100 feet, from 1,150 to 1,050 feet, approximately, above the present sea level. Beaches and deltas referable to this glacial lake are found, as described by Dr. A. C. Lawson,* in Duluth and its vicinity and on Mt. Josephine, near Grand Portage, showing that the lake while outflowing to the St. Croix had been extended, by the recession of the ice-sheet, along all the northwestern shore of lake Superior in Minnesota; but it may well be doubted whether it continued far into Canadian territory. Before the recession of the ice-sheet had uncovered the country about Port Arthur and farther eastward, probably its departure from Wisconsin and Michigan had permitted the glacial representatives of lakes Superior and Michigan to become confluent over the low divide of the Au Train and Whitefish rivers, the latter of which is tributary to the Little bay de Noc. The Western Superior glacial lake, suddenly falling about 60 feet, as is shown by the hights of successive beaches and deltas, then became merged in the glacial lake Warren,† outflowing at Chicago to the Des Plaines and Illinois rivers.‡

Dr. Lawson, in his report before cited, has not discriminated between the traces of the earlier lake outflowing to the St.

*"Sketch of the Coastal Topography of the North Side of Lake Superior, with Special Reference to the Abandoned Strands of Lake Warren." Minnesota Geol. Survey, Twentieth An. Rep., for 1891, pp. 181-289, with map, profiles, and figures from photographs.

†Named by Prof. J. W. Spencer in honor of Gen. G. K. Warren, Science, vol. xi, p. 49, Jan. 27, 1888; Proc. A. A. A. S., vol. xxxvii, for 1888, pp. 197-199; Trans., Roy. Soc. of Canada, vol. vii, for 1889, sec. iv, p. 122.

‡For my former discussions of the later stages of the glacial lakes and retreat of the ice-sheet in the St. Lawrence basin, see "Glacial Lakes in Canada," Bulletin, Geol. Soc. of America, vol. ii, for 1890, pp. 243-276; and "Relationship of the Glacial Lakes Warren, Algonquin, Iroquois and Hudson-Champlain," Ibid., vol. iii, for 1891, pp. 484-487.

Croix and those of lake Warren; but this seems desirable for convenience and definiteness in description and discussion. Many small glacial lakes, and a few as here attaining large size, became finally merged, by the retreat of the ice, in the single vast expanse of lake Warren, which stretched from Duluth eastward and southeastward to the west end of the basin of lake Ontario, covering the whole or the greater part of the four higher Laurentian lakes. In the western part of the lake Superior basin the ancient high shore lines, with their evidences of wave-erosion and deposition, belong, from hights (above the present lake) of 450 or 475 feet up to 607 feet, the highest observed by Dr. Lawson, to the Western Superior lake. Below these hights, the numerous lower shores mark successive stages of lake Warren, which were due only in very slight measure to erosion of its outlet, but which the present writer confidently believes to have been caused almost entirely by a progressive uplift of this region, elevating the northern and northeastern parts of the area of the great glacial lake, while its outlet and some southwestern portions of its area remained with little or no change of hight.

A quite different view is given by Dr. Lawson, who thinks that lake Warren was not held in by the retreating ice-sheet, but by land barriers, the country on the south and east having been relatively higher than now, and that the differential subsidence of the land there and contemporaneous uplifting of the country about Hudson bay went forward without disturbance of the horizontality of the old shore lines enclosing lake Superior. On the west, however, I have ascertained for the southern half of the area of the glacial lake Agassiz, in the basin of the Red river and of lake Winnipeg, that it experienced a differential uplift increasing about one foot to the mile from south to north during the departure of the ice-sheet. On the east, Mr. Frank Leverett has demonstrated that the beaches of lake Warren south of lake Erie were contemporaneous with the accumulation of adjacent moraines;* and the basin of lake Iroquois, the glacial expansion of lake Ontario, according to levelling by Gilbert and Spencer, has been uplifted like that of lake Agassiz, but with a greater northward ascent of the old Iroquois beach, amounting to five feet per mile for fifty miles from Rome to near Watertown, N. Y. It seems therefore improbable, in the first place, that lake Warren occupied a land-

*Am. Journ. of Science, III, vol. xliii. pp. 281-301, with maps. April, 1892.

locked instead of an ice-dammed basin, and, secondly, that these recent differential epeirogenic† movements on each side failed to extend across the area of lake Superior.

The great Pleistocene lakes Agassiz, Warren, Algonquin, and Iroquois, were probably due alike to the barrier of the waning ice sheet; and their basins appear to have shared in a general epeirogenic uplift of the whole drift-bearing area of our continent, when it was relieved from its ice burden. Under this view, the highest shores at Duluth and on Mt. Josephine seem readily referable to an ice-dammed lake in the western part of the Superior basin outflowing in the eroded channel at the head of the St. Croix river, from which there is an ascent of about 140 feet in a distance of 120 miles northeast to the 607 feet shore terrace noted by Lawson on Mt. Josephine. Later, for the earliest and highest stage of lake Warren, likewise ice-dammed, with outlet to the Mississippi across the low divide at Chicago, about 595 feet above the sea, we have now an ascent of 420 feet in about 350 miles to the highest shore found by Lawson near the Sault Ste. Marie, at a hight of 414 feet above lake Superior. The differential uplifts thus indicated for both of these old lake shores are similar in their vertical amount and geographic extent with the fully known epeirogenic uplift of the lake Agassiz area.

BEACHES.

The upper limit of lacustrine action in Duluth and its vicinity is marked by discontinuous beach deposits on the upper part of the steeply ascending bluffs at an altitude of 535 feet to 540 feet above the lake. In the recess between two projections of rock at the top of the Seventh Avenue inclined railway, where the hight of this shore was determined by Dr. Lawson, it appears as a small terrace of sand and fine and coarse gravel, 12 to 15 rods long and about 5 rods wide. The verge of its flat surface is on the level of the railway station floor, and thence the terrace rises four or five feet to where it adjoins the till and rock slopes. In front the same gravel and sand fall off about 20 feet within a few rods, and then spread out again in a similar lower and longer terrace, eight to ten rods wide, with its surface gently inclining lakeward at 515 to 505 feet, approximately. These

---

†The terms *epeirogeny* and *epeirogenic* (continent-producing, from the Greek *epeiros*, a mainland or continent) are proposed by Mr. G. K. Gilbert (in "Lake Bonneville," Monograph I, U. S. Geol. Survey, 1890, p. 340), to designate the broad movements of uplift and subsidence which affect the whole or large portions of continental areas and of the oceanic basins.

deposits were brought partially by inflowing waters from above, being so far of delta character, and partially by shore currents from wave erosion of the adjoining bluffs on each side, being for such portion more strictly beach accumulations. They mark stages of the Western Superior lake when its mean levels here were about 535 and 510 or 515 feet above lake Superior.

Next below these shore lines is the most definite and persistent beach of the entire series, both of the Western Superior lake and the ensuing lake Warren. This was generally represented along the bluff face by a narrow beach terrace or slight shelf, less steep than the slopes below and above it, so that its contour line, 470 to 475 feet above the present lake, has been used as the course of a driveway, known as "the boulevard," which has been graded and is much used for pleasure driving, along an extent of four miles, above the principal part of the city of Duluth, from Miller's creek to Chester creek. Beyond these limits the boulevard is planned to be extended for distances of four miles more, both to the southwest and northeast, following the same altitude and shore line, giving a total length of twelve miles. Its hight is only a few feet above the water divide in the old channel of outflow from the Western Superior lake to the St. Croix; but, if we make due allowance for the partial filling of that channel with postglacial alluvium and peaty swamp deposits, it seems probable that this latest shore of that glacial lake has now an ascent of 15 or 20 feet in the distance of about 25 miles from its outlet north-northwest to Duluth. The earlier and higher shores here were made when the erosion of the outlet lacked successively about 65 and 30 or 35 feet of its final depth; but a certain part of its earliest erosion had been done before the retreat of the ice extended the lake to this northwest coast. These three beaches of the Western Superior lake may be conveniently designated as the First and Second Duluth beaches and the Boulevard beach.

Between the neighborhood of Duluth and Mt. Josephine, no definite observations of the Western Superior glacial lake shore lines have been obtained, although there can be no doubt that they extend continuous along this distance, which is about 130 miles in a nearly direct northeastward course. When the woods of this high coast shall be cleared off, as will probably sometime be done in many places for farming and pasturage, the beach levels will be observed, especially the highest and lowest of the three noted at Duluth. Attempting to correlate

these beaches with those found by Lawson on Mt. Josephine, I identify the 535 feet and 510 to 515 feet Duluth shores as respectively his 607 and 587 feet shores; and the 475 to 470 feet beach of the Duluth boulevard becomes apparently the conspicuous 509 feet beach of Mt. Josephine. The total differential uplifting of the two upper shores between these localities has been about 70 feet, of which about half had been accomplished previous to the time of the Boulevard beach. This progressive uplifting of the land soon after the recession of the ice, while indeed the ice barrier yet remained in the eastern part of this lake basin, is in full parallelism with the epeirogenic movements which gave their northward ascents to the beaches of lakes Agassiz and Iroquois, and, as Prof. J. W. Spencer and Mr. F. B. Taylor have shown, to the beaches of various portions of lakes Warren and Algonquin.

During the past season's field work I obtained numerous observations of the beaches of the Western Superior lake near Thomson, and between Carlton and Wrenshall, some 15 miles southwest of Duluth, and in the vicinity of Holyoke, a station of the Great Northern railway, 15 miles south of Carlton. Near Holyoke, which is about 30 miles west of the outlet at the head of the Bois Brulé and St. Croix rivers, the successive lake levels indicated by the beach ridges observed and provisionally referred to the Western Superior lake are about 520, 500, and 455 feet above lake Superior, corresponding well with the slightly inclined planes of the Duluth and Mt. Josephine shores, and indicating a lowest water surface of about 455 feet at the outlet.

Eight beaches of lake Warren, mostly on the same levels with its well defined deltas, were also observed in the vicinity of Duluth, on the Northern Pacific railroad from West Superior to Wrenshall, and on the Great Northern railway to the vicinity of Rhodes' Mill, four miles northeast of Holyoke. The highest three of these shore lines bear conspicuous deposits of beach sand and gravel which are cut by the railroad, the first being one and a half miles southeast of Wrenshall, the second nearly a mile farther east, and the third close west of Barker station, about a half mile east from the last. The altitudes of their crests at the railroad cuts are respectively 427, 401, and 361 feet above lake Superior; and the mean water levels of lake Warren while these deposits were being accumulated appear to have been approximately at 410, 385, and 350 feet. Of these the first, which was the highest level of lake Warren,

held during only a very short stage, is represented by the fourth in the series of deltas of Chester creek in Duluth; and the second and third have their representation in the fifth of those deltas, while apparently the second is the Nelson beach, and the third the McEwen beach, of Mr. F. B. Taylor's observations along the south side of lake Superior, north of lake Huron, and in the vicinity of lake Nipissing.* The Nelson beach, generally marking the highest well defined shore of lake Warren, is 410 feet above lake Superior at Houghton, Michigan; 414 feet near the Sault Ste. Marie; and 538 feet, or 1,140 feet above the sea, near North Bay, lake Nipissing. The McEwen beach, supposed to have been formed when lake Warren at Duluth stood about 350 feet above lake Superior, is identified as the 365 feet shore terrace at Ste. Marie, while near lake Nipissing its hight from the same plane is 488 feet, being 1,090 feet above the sea level. In Dr. Lawson's series of observations, the higher and earlier shore of 410 to 415 feet near Wrenshall and at Duluth seems to be probably represented by the 440 to 458 feet plain and terrace at Grand Portage, and by the 455 feet terrace of an old delta plain on the Kaministiquia river; and near lake Nipissing, according to my correlation with Mr. Taylor's notes, it is found about 1,205 to 1,220 feet above the sea.

To present concisely the results of my studies of the whole series of lake shores observed by me at and near Duluth, in their probable correlations with the shores observed farther eastward by Dr. Lawson, Mr. Taylor, and Prof. Spencer,† notes of the twelve lake levels found here are successively presented as follows, in descending order, their altitudes being given in feet above lake Superior. On northern portions of the lake Superior coast several of these seem to be each represented by two or more shores, separated by distinct vertical intervals of 10 feet or more. Most of the beaches, it should be remarked, are very feebly developed, even in the most favorable situations for their formation, and are not discernible along the far greater part of all the lake borders. During all the time of uplifting of the basin and sinking of the water surface by its finding successively lower outlets and by their erosion

*Bulletin, Geol. Soc. America, vol. v, pp. 620-626, with maps, April, 1894. Am. Geologist, vol. xiii, p. 220, March, 1894; and 316-327 and 365-383, with maps, May and June, 1894. Am. Jour. Sci., III, vol. xliii, pp. 210-218, March, 1892.

†J. W. Spencer, Am. Jour. Sci., III, vol. xli, pp. 12-21, with map, Jan., 1891; same vol., pp. 201-211, with map, March, 1891. Bulletin, Geol. Soc. of America, vol. ii, pp. 465-476, with map, April, 1891.

from higher to lower levels, whenever the diminishing lacustrine area was nearly unchanged for a few years or longer, the erosion and deposition effected by the great waves of storms, and the tribute of streams forming deltas, recorded these shore lines.

BEACHES OF THE WESTERN SUPERIOR GLACIAL LAKE.

First Duluth beach: at Duluth, 535 feet above lake Superior; on Mt. Josephine, 607 feet; at Kimball, Wis., 570 feet; at L'Anse and Marquette, Mich., about 590 feet.

Second Duluth beach: at Duluth, 510 or 515 feet; on Mt. Josephine, 587 feet.

Boulevard beach: at Duluth, 470-475 feet; on Mt. Josephine, 509 feet.

BEACHES OF THE GLACIAL LAKE WARREN.

Belmore beach (name given by Prof. N. H. Winchell to the corresponding earliest shore line of lake Warren in Ohio†): near Wrenshall and in Duluth, 410-415 feet; at Grand Portage, 440 feet; on the Kaministiquia river, 455 feet; at Mackenzie, on the Canadian Pacific railway 13 miles northeast of Port Arthur, Dr. Lawson's descriptions indicate that this lake level, at about 475 feet, adjoined the melting ice-sheet (l. c., p. 264); eight miles east of Cartier, about 600; southeast of lake Nipissing, 605-620. The "Ridgeway beach" of Prof. Spencer.

Nelson beach (named by Taylor in the vicinity of North Bay, lake Nipissing; probably united with the Belmore beach in Ohio and northward to Mackinac island): at Duluth, 385 feet; at Mackenzie, a morainic terrace, 420 feet; at Jackfish bay, 418; Sault Ste. Marie, 414; Houghton, 410; North Bay, 538. The "Algonquin beach" of Mr. Taylor on Mackinac island, at 185 feet; near Petoskey, about 80 feet; and at Traverse City, 60 feet. The hights (likewise above lake Superior) of this shore about Green bay of lake Michigan are noted by Mr. Taylor as follows: at Green Bay, 0; six miles north of Menominee, 30 feet; South Bay hill, 115 feet; Cook's Mill, near the head of Big bay de Noc, 150 feet.

McEwen beach (named by Taylor near North Bay): at Duluth, 350 feet; Schreiber and Terrace bay, 391-2; Sault Ste. Marie, 365; North Bay, 488.

Thibeault beach (also named by Taylor near North Bay): Great Northern railway, about 2¼ miles northeast of Foxboro, 290-300 feet; Mt. Josephine, 313; Mackenzie, 327; Sault Ste. Marie, 311.

Double Bay beach: at Duluth, 255-260 feet; at Double bay, 279 feet; on Isle Royale‡, about 270; Carp river, 288.

First Beaver Bay beach: at Duluth, 155-160 feet; at Beaver bay, 173 feet; eastward represented by two beaches:—*a*, at Grand Portage, 232 feet; at Carp river and Pie island, 222; at Terrace bay, 243; at Sault Ste. Marie, 224; on the Keweenaw peninsula, 220;—*b*, at Mazokamah, 214; Terrace bay, 228: Dog river, 216; Sault Ste. Marie, 208; on the Keweenaw peninsula (Taylor and Lane), about 200.

†Proc. Am. Assoc. for Adv. of Sci., vol. xxi, for 1872, pp. 171-179. Geology of Ohio, vol. ii, 1874, pp. 56, 418, 433.

‡Altitudes of this and other lower shore lines on Isle Royale are kindly supplied by Dr. A. C. Lane, from unpublished observations for the Geol. Survey of Michigan.

Second and Third Beaver Bay beaches (becoming three northeastward): at Duluth, 85-90 feet; Beaver bay, 126 and 115; Pigeon river (third), 134; Isle Royale, about 130; shore above Carp river, 164, 128, and 122; Port Arthur (third), 149; Silver Islet, 168, 161, 149; Jackfish bay, 176, 158: Sault Ste. Marie, 150; Keweenaw peninsula, 170, 150, 145-125 (delta of Huron creek, A. C. Lane).

Chester Creek beach: at Duluth, 45-50 feet; Beaver bay, 80; Isle Royale, 90; McKellar's point, 101; Port Arthur, 118; Nipigon, 132; Montreal river, 135; Mamainse, 122.

BEACH OF THE GLACIAL LAKE ALGONQUIN.

Algonquin beach (named by Prof. Spencer, in Proc. A. A. A. S., vol. xxxvii, p 199): at Duluth, united with the present lake beaches; at Beaver bay, 20 feet; Good Harbor bay, 27; Grand Portage, 38; McKellar's point, 48; Carp river, 52; Pie island, 43; Port Arthur, Nipigon, and Montreal river, 61; Sault Ste. Marie, 49; Houghton and Marquette, about 25; near Algoma, 60-80; near North Bay, on lake Nipissing, 140. The Nipissing beach of Mr. F. B. Taylor; but not his "Algonquin beach" on Mackinac island (Am. Jour. Sci., III, vol. xliii, pp. 210-218), which is the highest of the lake Warren shores, being apparently the compound representative of the Belmore and Nelson beaches.

The front of the departing ice-sheet was the barrier of the Western Superior glacial lake while the one receded and the other advanced from Duluth northeastward to Mt. Josephine and the most northeastern point of Minnesota, and eastward to Marquette. When the farther glacial recession opened the space for this lake and the similarly expanding lake Warren to be merged together above the low land of the eastern part of the Michigan upper peninsula, the Western Superior waters fell about 60 feet below their former outlet to the St. Croix, and thenceforward the outlet of lake Warren past Chicago carried away the drainage from the glacial melting and rainfall of the Superior basin. At a time that was probably somewhat later than the end of the Western Superior lake, its analogue. the Western Erie glacial lake, which had outflowed past Ft. Wayne, Indiana, to the Wabash, Ohio, and Mississppi rivers, became likewise lowered and merged in lake Warren, which in its soon ensuing maximum stage stretched from the south end of lake Michigan to the north side of lake Superior, northeast to lake Nipissing, and eastward to the east end of lake Erie and the southwestern limits of the lake Ontario basin. While the outlet continued at Chicago, all the northern part of the area of lake Warren, extending about 600 miles from Duluth to lake Nipissing, was uplifted hundreds of feet.

The uplifting was approximately uniform for this entire extent, and indeed for the whole width of the Superior basin,

reaching 150 miles from south to north; so that the present altitudes of the elevated beaches, while somewhat inclined, are yet through long distances so nearly horizontal that they partially and in a remarkable degree justify Dr. Lawson's opinion that the ancient lake levels remain parallel with that of to-day. The sum of all the epeirogenic movements since the formation of the Belmore and Nelson beaches, along a nearly due north line measures as follows, in comparison with the Chicago outlet: from Chicago for about 185 miles north to the southern end of Green bay, very little, the old shore still being nearly unchanged; about the north end of Green bay, at the head of the Big bay de Noc, 150 feet; at Houghton, on the Keweenaw peninsula, 410 feet; and at the north side of lake Superior, 420 feet, or more probably 475 feet. Along a west to east belt 50 to 100 miles wide, including the upper peninsula of Michigan, the rate of differential uplifting ranged from one to five feet per mile from south to north; while on a large area farther north there was little differential movement, but in general a surprisingly uniform and regular elevation of the lake Superior district.

When the glacial melting and retreat at length permitted an outflow from the St. Lawrence basin over a lower pass, which was through central New York to the Mohawk and Hudson, the water surface of the basins of lakes Michigan, Huron, and Superior, fell only some 50 or 75 feet, from the latest and lowest stage of lake Warren to its short-lived successor, lake Algonquin. This lake was ice-dammed only at low places on its east end, as at or near the heads of the Trent and Mattawa rivers, lying respectively east of lakes Simcoe and Nipissing, where otherwise its waters must have been somewhat further lowered to outflow by those passes. A careful study of the late glacial epeirogenic uplifting of all portions of the St. Lawrence drainage area, as known by the present inclinations of its many shore lines, convinces me that Gilbert* and Wright† have overestimated the importance of the outflow, if any such took place, from lake Algonquin past the present lake Nipissing to the Mattawa and Ottawa rivers. Professor Spencer's Algonquin beach is very clearly the Nipissing beach of Mr.

*Proc. Am. Assoc. for Adv. of Science, vol. xxxv, for 1876, pp. 222, 223. "The History of the Niagara River," Sixth An. Rep. of the Commissioners of the State Reservation at Niagara, for the year 1879, pp. 61-84, with maps and sections (also in the Smithsonian An. Rep. for 1890, pp. 231-257).

†Bulletin, Geol. Soc. of America, vol. iv, pp. 423-5; with ensuing discussion by Dr. Robert Bell, pp. 425-7.

—5

Taylor; and this earliest and principal stage of lake Algonquin is shown by these beaches to have coincided closely in area with lakes Michigan and Superior, but to have been considerably more extensive eastward than the present lake Huron and Georgian bay. It held a level which now by subsequent differential epeirogenic movements is left probably wholly below the present level of lake Michigan by a vertical amount ranging from almost nothing to about 40 feet. Its shores were nearly coincident with the western shore of lake Huron, but eastward they are now elevated mostly 150 to 200 feet above that lake and Georgian bay; and in the lake Superior basin they vary from about 50 feet above lake Superior at its mouth, and along its northeastern and northern shores, to 25 feet at Houghton, and to a few feet or none at Duluth. The earliest outflow of lake Algonquin doubtless passed southward by the present course of the St. Clair and Detroit rivers; thence it ran east as a glacial River Erie, following the lowest part of the shallow bed of the present lake Erie, which then had an eastward descent of probably 200 feet, allowing no lake or only a very small one to exist in the deepest depression of the basin; and north of Buffalo it coincided with the course of the Niagara river.

The Niagara gorge has since been eroded by the recession of its waterfall; and the outflow from the upper Laurentian lakes has been constantly pouring over the receding cataract, excepting possibly (but improbably) that it may have been diverted for some very short time, as less than a century, to the Mattawa. It seems to me far more probable that the epeirogenic uplift of the Nipissing region, which had elevated it about 450 feet during the existence of lake Warren, continued so fast that both the Trent and Nipissing-Mattawa passes were raised above the level of lake Algonquin before the glacial retreat uncovered the country east of them so that outlets could be obtained there.

With the continuance of the uplift of the lake Superior basin after the formation of the Algonquin beach, the mouth of lake Superior and the Sault Ste. Marie came into existence; and this movement allowed the lake level at Duluth to fall probably 40 or 50 feet beneath the Algonquin and present shore line. Subsequent differential elevation of the eastern and northern parts of the basin, as compared with Duluth, has again brought the west end of the lake up to the Algonquin shore; but not until the St. Louis river, while the water surface

stood considerably lower than now, had deeply eroded its broad channel through the very gently sloping expanse of till from Fond du Lac to the harbor of Duluth and Superior.

It would be very interesting to trace the relationship of the epeirogenic uplifting of the lake Warren basin with those of the contemporaneous lake Agassiz on the west and the slightly later lake Iroquois on the east, but the limits and scope of the present report forbid this. Nor can we here consider what these glacial lakes teach concerning the recession of the ice-sheet from New York and New England, which are thus clearly shown to have been the last portion of the United States, at least eastward from the Rocky mountains, to be uncovered from the fast waning continental glacier. The retreatal moraines of all the drift-bearing area east of the great angle of the drift boundary in southwestern New York appear, in the light of these studies, to be somewhat (though not many hundreds of years) newer than all the series of moraines within the limits of the United States west from that angle to Minnesota and North Dakota.

DELTAS.

Not only the St. Louis river, but also many small streams in the vicinity of Duluth, brought noteworthy deltas of gravel and sand into the formerly much higher glacial lakes which represented lake Superior. The largest delta plain which I observed reaches about a mile eastward from the St. Louis river at Thomson and has an altitude of 455 to 460 feet above the present lake. It was probably formed nearly at the old lake level or within a few feet below it, contemporaneous with the formation of the Boulevard beach. Still water deposits, laid down at a short distance off shore, swept by the prevailing winds and shore currents southward from the mouth of the St. Louis, as it then was, are now found as the beds of stratified clay worked for brick-making at and near Wrenshall, three to four miles south of this delta. Numerous other sand and gravel deltas of the St. Louis, mostly of small extent, will doubtless be easily recognized by adequate search; and the corresponding finer silts borne southward thinly cover many tracts of the wooded Nemadji drainage area, above its much greater thickness of till.

On Tischer's creek, in the northeastern suburbs of Duluth, large terrace remnants of a delta which was brought in during the stage of the First Duluth beach are found at 540 to 550 feet,

about a quarter to a third of a mile north of the Hardy School. Other and lower deltas of this stream lie west of this school house and within a quarter of a mile south.

The most interesting series of deltas, however, which I examined in Duluth is situated along the course of Chester creek. Besides its present course, this creek sent a part of its waters into the Western Superior glacial lake by a more western channel, occupied by a very small brook, there depositing the conspicuous gravel and sand banks above and below the boulevard a half mile southwest of Chester creek, which are now being extensively excavated by the city street department and in part for use as masons' sand. Along Chester creek I noted nine successive delta terraces or small plains, usually well represented on each side of the creek, which has cut deeply through them to the underlying rock or steep till slope. In their descending order, these have the following altitudes:

1. About 540 to 530 feet; belonging to the First Duluth stage.
2. About 510 to 490 feet; representing the Second Duluth beach.
3. At 480 to 460 feet; deposited during the time of the Boulevard lake level.
4. At 420 to 410 feet; the Belmore level.
5. From 380 to 350 feet; representing together the Nelson and McEwen beaches.
6. From 260 to 230 feet, including the former site of the Forest Hill cemetery; the Double Bay beach. (Probably a delta deposit may be found nearly midway between the last two, at the Thibeault shore line.)
7. At 160 to 150 feet; on the first Beaver Bay shore line.
8. At 90 to 75 feet; corresponding to the Second and Third Beaver Bay beaches.
9. At 50 to 45 feet, close to the mouth of this creek, and rising immediately on the north side of the Duluth & Iron Range railroad. From this delta is derived the name of the Chester Creek beach.

After examining this series of deltas and mapping their locations, the altitudes here noted were obtained from a large scale contoured map of Duluth in the office of Mr. D. A. Reed, the city engineer.

IV.

PRELIMINARY REPORT OF FIELD WORK DURING 1893 IN NORTHEASTERN MINNESOTA.

BY ULYSSES SHERMAN GRANT.

CONTENTS.

ITINERARY.

During the last week in June and the first in July the writer accompanied Prof. N. H. Winchell on a trip along the north shore of lake Superior from Grand Marais to the end of Pigeon point and return. Quite a number of the more important localities along this shore were examined, an account of which will be given by Prof. Winchell. After returning to Grand Marais another trip of ten days was made northward and northwestward, by what is known as the "Iron trail," to Brulé lake and

thence to Gunflint lake, where a week was spent in examining the iron-bearing rocks in T. 65-4.* In the first part of August the writer participated in the excursion of the Geological Society of America through the mining regions of Michigan. On returning to the field in the last part of August the region of Gunflint lake and that west, south and east of this lake was examined, and data were obtained for a geological map of this region. This work continued until the early part of October, when a few days were spent in company with Messrs. N. H. and H. V. Winchell in visiting some of the critical exposures near Tower.

MAPPING ACCOMPLISHED.

At the beginning of the season the writer was assigned that part of Minnesota lying in ranges 2-7 west of the Fourth principal meridian to map geologically and topographically. Of course it was impossible, with the time and assistance allowed, to cover all this area (over 1500 square miles) much more carefully than already had been done; consequently that part lying between T. 63 and lake Superior was neglected and the work was concentrated on the rest of the area.

The part of the Mesabi range in this portion of the state was divided into three divisions (plates), in which more detailed work was done than on the rest of the region, and in each division the vicinity of the outcrop of the iron bearing rocks received more attention than the rest of the plate. These plates and their approximate areas are as follows:

Plate 80.—Ts. 63-64, Rs. 6-7; 144 square miles; Fraser Lake plate.
Plate 81.—Ts. 64-65, Rs. 4-5; 143 square miles; Akeley Lake plate.
Plate 82.—Ts. 64-65, Rs. 2-3; 101 square miles; Gunflint Lake plate.

The amount of mapping accomplished is outlined in the two following sections.

I. TOPOGRAPHY.

This part of the work was done under the direction of the writer by Messrs. C. P. Berkey, L. A. Ogaard and Alex. N. Winchell. Mr. Berkey, who was in charge of this work during July and August, was in the field from June 26th to September 2d;† Mr. Winchell from June 26th to August 26th; Mr. Ogaard from June 26th to October 5th, but during September and October considerable of his time was devoted to other duties.

The altitudes of all the principal lakes, and of a large num-

*In this paper the "Range" is always *west* of the Fourth principal meridian.

† Mr. Berkey has written an account of his work on the topography, which appears later in this volume.

ber of the smaller ones, were ascertained accurately by levelling from lake Superior.* By means of aneroid barometers and hand levels data were obtained for the drawing of contour lines, which are fifty feet apart. The topographical work on that part of the Mesabi range mapped by the above mentioned party is much more accurate than that done by parties of the survey further west, for two reasons; first, the levels of the lakes were accurately determined, and second, these lakes were used as checks on the aneroids every few hours. The results of the work of 1893 and that of the writer for 1892 are as follows:

Plate 80.—Levels of most of the lakes by barometrical readings; location of the prominent hills; very little accurate contouring. This, however, is an unimportant sheet.

Plate 81.—Practically complete, excepting some of the northwestern part.

Plate 82.—Practically complete.

In the region south of these plates, except in the vicinity of Brulé and Ida Belle lakes where the contouring is nearly complete, very few data have been obtained. To the north of these plates the levels of almost all the lakes are known, mostly by aneroid readings, and some contouring has been done. The hights of the lakes between Gabemichigama lake and Ely (by way of Knife and Basswood lakes) were obtained by level.†

II. GEOLOGY.

In the mapping of plates 80, 81 and 82 the writer found it necessary to go over the entire ground anew and depended but very little on the mapping of former parties of the survey, as their work was more in the nature of a reconnaissance than of accurate mapping. In addition to a careful survey of the lake shores, with very frequent trips inland, nearly all north and south section lines were followed in the vicinity of the iron-bearing rocks and the Animikie, and occasionally sections were crossed one to four times. The mapping done during the last two seasons and some in 1891 is as follows:

Plate 80.—Practically complete, but less time was devoted to

*The levelling was done by Mr. L. A. Ogaard, assisted by Alex. N. Winchell. The writer can vouch for the care and accuracy with which this work was done, sometimes under decidedly embarrassing circumstances.

†The hights of many of the lakes and points in the area here reported on can be found on pages 22-25 of Mr. Warren Upham's report in this volume; also in the report of Mr. C. P. Berkey.

this plate than to the others as it is very largely covered by gabbro.

Plate 81.—Practically complete.

Plate 82.—Practically complete.

In the region south of these plates, except around Brulé and Ida Belle lakes and in T. 62-6, nothing has been accomplished since the publication of the geological map in bulletin number 6. The mapping of the region north of these plates is practically complete. Special attention has been given to the vicinity of Kekequabic lake, of which a map has been published (see the 21st Ann. Rept., pl. I), and to the outlines of the Saganaga granite (see the 20th Ann. Rept., pp. 83–95). The lakes lying between Ogishke Muncie and Ottertrack lakes have been examined and work supplementary to that of the former parties of the survey in this region has been done.

SKETCH OF RESULTS OF GEOLOGICAL WORK.

While opportunity has not been had for a careful examination of the specimens collected during the last two years, and for the preparation of a report on this region, still there are some points, which were brought out by the field work and some little study since, that are sufficiently clear to warrant a preliminary statement of the results reached.

I. THE KEEWATIN.

The lakes south of Ottertrack lake in T. 66–6 and the north half of T. 65–6 have been examined and the rocks found to be of the usual Keewatin strata with some areas that consist of volcanic tuff. Large and beautiful exposures of Ogishke conglomerate occur on the shores of the lake in S. W. ¼ sec. 36, 66–6.

The Keewatin in the northern part of the southern half of Ts. 65–4 and 65–5 is composed almost entirely of greenstone and greenstone schists. Some of these greenstones show fragmental materials and are probably of the nature of volcanic tuff, while other parts are undoubtedly massive eruptives.

The outlines of the Saganaga granite in Minnesota have been traced, and abundant evidence has been found to show the eruptive nature of this granite in the Keewatin rocks. Part of this evidence has been published* for the western edge of this granite area, and during the last two years facts pointing the same way have been noted along the southern edge of this

* U.S. Grant. 20th Ann. Rept., pp. 83-95, 1893. Amer. Geol., vol. x, pp. 4-10, 1892.

granite where it comes in contact with the greenstone. The proofs of the eruptive nature of the granites of Saganaga, Kekequabic and Snowbank lakes and of the Giant's range have been stated before by the writer,* and in the case of the Kekequabic lake granite the matter has been treated in some detail.† Mr. J. E. Spurr, who has been at work for the survey on the Mesabi range west of the Duluth and Iron Range railroad during the last summer, also states that there is abundant evidence of the intrusive and metamorphosing nature of the granite of the Giant's range in that district.‡

It frequently happens, that, where these granites come in contact with the surrounding rocks, schists more crystalline than those of the usual Keewatin occur. To these more crystalline and completely crystalline schists the Minnesota survey has applied the term *Vermilion*, which is regarded as a synonym of Dr. A. C. Lawson's *Coutchiching*. The Vermilion rocks have been supposed to occupy a distinct stratigraphical position below and older than the Keewatin. The writer has already called attention to the fact that in the region of the Kawishiwi river (Ts. 63–9, 63–10 and 63–11 W.) there seem to be good reasons for not separating the rocks mapped as Vermilion from the Keewatin.§ During the field work of the past two seasons additional facts have been collected concerning these more crystalline rocks (Vermilion), facts sufficient to justify the statements (1) that the rocks called Vermilion in the region of the writer's field work are not necessarily lower in the geological scale than the Keewatin, but that they occur at various horizons in the Keewatin, (2) that they are only a more crystalline condition of these same Keewatin rocks, and (3) that they probably owe their more crystalline nature largely to their close proximity to areas of intrusive granite. It will be noticed that the Vermilion rocks as mapped usually occur between areas of Keewatin and granite; in this connection consult especially plates 10 and 11 of Bulletin No. 10 and the geological map accompanying Bulletin No. 6. And, as stated above, some of these granite areas are known to be intrusive, and very probably others not mentioned above are of the same nature. The gradual transition from the Keewatin to the Vermilion rocks has been described by Messrs. N. H., A. and H. V. Winchell in

* 20th Ann. Rept., pp. 37-38, etc., 1893.

† 21st Ann. Rept., pp. 37-38, 50-54, 1893.

‡ Bull. No. X. p. 2, 1894.

§ 20th Ann. Rep., p. 59, 1893.

the more recent and annual reports of the survey and more especially in Bulletin No. 6. The same conclusions in regard to the relations and position of the "Vermilion" rocks of the western Mesabi iron range were reached independently by Mr. J. E. Spurr† during the last summer.

It would be unwise to extend these conclusions concerning the "Vermilion" rocks in the areas studied by the writer to all similar rocks in northeastern Minnesota and western Ontario; but it does not seem improbable that these conclusions will in the future be found to apply to a large part, if not to the whole, of the so-called "Vermilion" rocks of the northeastern part of this state.

II. IRON-BEARING ROCKS OF AKELEY LAKE.

These rocks lie upon the Keewatin greenstone to the north and on the south are overlain by the great gabbro mass. They extend in a narrow belt from near the center of the N. ½ sec. 27, 65–4, westward nearly to the western edge of the N. ½ sec. 34, 65–5 (a distance of about six and a half miles). West of this they are met with in a few isolated outcrops near the northern edge of the gabbro, or included in the gabbro, and at Birch lake (T. 61-12) apparently the same rocks reach a considerable development and have been exploited for iron ore. In Ts. 65-4 and 65–5 these rocks outcrop in a belt from 300 to 1300 feet in width, and the dip varies from almost vertical to 20 degrees toward the south, the average dip being 45–50 degrees. Where the belt is the widest the dip averages about 30 degrees; this would make a thickness of 650 feet, which is probably the maximum thickness of these beds in the vicinity of Akeley lake.

The iron ore of these rocks is a magnetite, making on the average a rather low grade bessemer ore, with no titanium. During 1892 and 1893 considerable work was done by the Gunflint Lake Iron Company in sections 28 and 29, 65–4, and a railroad was completed from Port Arthur to their headquarters in sec. 28. A number of test pits have been dug and two shafts have been sunk, the deeper of these is in the S. E. ¼ N. W. ¼ sec. 28; in September, 1893, it had reached a depth of 112 feet. As yet no ore has been shipped and no bed of any considerable thickness of clean ore has been encountered, although by sorting by hand a fair quality of ore can be obtained.

Prof. N. H. Winchell considers these rocks to belong to the

† Cf. Bull. 10, p. 2, and the explanations to plates 10-12.

lower part of the Animikie,* while Dr. W. S. Bayley has included them in the gabbro.† In this preliminary report the origin of these ore-bearing rocks and their relations to the Animikie and to the gabbro will not be discussed, (See remarks concerning the absence of a basal quartzyte at Gunflint lake on pages 74-75 of this report).

III. ANIMIKIE.

During the season of 1893 considerable new data were obtained concerning the Animikie rocks in the vicinity of Gunflint lake, and it is now possible to construct a much better geological map of this region than has hitherto been published.‡

The Animikie rocks about Gunflint lake have been little disturbed; they dip, with local exceptions, at an angle of 8 to 10 degrees a little east of south. In the immediate vicinity of the gabbro the dip increases and as the slates disappear under this rock it occasionally reaches 20 to 30 degrees. On the north side of the lake, where the lower beds lie upon the older vertical crystallines, there has been some gentle bending of the later rocks, and in the S. ½ sec. 21, 65-4, is a sharp synclinal, on whose southern side the Animikie slates stand almost vertical.

Faults.

The country is made up of parallel ridges trending east and west. On the south side of each ridge gentle slopes occur, but on the north steep, mural descents are seen. The tops of the ridges are composed of diabase sills, which usually cap a considerable thickness of slates. This structure has given rise to the idea that there has been a series of monoclinal uplifts along east and west fault lines, the downthrow occurring on the north side of each fault. While this idea is very plausible as long as topography alone is concerned, still it seems to find little or no confirmation in the sequence of the strata. The Animikie rocks, as stated beyond, can be readily divided into three divisions, and each division is well characterized lithologically. Such being the case it would be a comparatively easy matter to recognize any member if brought out of its normal position by faulting, but in no instance has the writer been able to do this. There seems to be good evidence that no great faults have occurred, although minor ones of comparatively small throw may exist.

*16th Ann. Rept., pp. 82-89, 1888. See especially Bulletin No. 6, 1891.

†19th Ann. Rept., pp. 194-210, 1892. Journ. of Geol., vol. i, p. 694, 1893.

‡The best map yet issued is that by Irving and Van Hise in their work on the Penokee range, 10th Ann. Rept. U. S. Geol. Sur., pl. xliii, 1890; and Mon. XIX, pl. xxxvii, 1892.

Thickness and divisions.

It is easy to separate the Animikie rocks at Gunflint lake into three well marked lithological divisions, and perhaps each of these can be subdivided. Below is given this three fold division, with the estimated miximum thickness of each.*

The upper, or graywacke-slate, member.—Composed of black to gray slates and fine graywackes, with some flinty slates; the upper part shows coarser detrital matter, and the highest beds seen are fine grained quartzytes and quartz slates. Thickness 1,900 feet.

The middle, or black slate, member.—Composed largely of black slates, often very fissile, and apparently carbonaceous. At the bottom of this member is a distinct division of black to gray slates which are fine grained, siliceous and often flinty; they reach a thickness of some 60 feet. They are as distinctly marked off from the black, carbonaceous slates above as from the iron-bearing rocks below, and perhaps might be put in a separate member by themselves, but they seem to be distinctly differentiated only at the western end of Gunflint lake. Thickness of middle member 1,050 feet.

The lower, or iron-bearing, member.—Composed largely of jaspery, actinolitic, siliceous and magnetitic slates, usually quite thinly laminated, and some beds of cherty carbonate and of lean iron ore. The presence of thin bands rich in magnetite is a very characteristic feature of this member. It is also characterized by greenish to reddish siliceous rocks, often spotted and forming jaspers; to similar rocks on the western Mesabi range Mr. H. V. Winchell† has applied the name "taconyte," and Mr. J. E. Spurr‡ has shown that they were originally composed largely of glauconitic greensands, and that in some cases the glauconite still remains. Thickness of the lower member 900 feet.

The quartzyte (Pewabic) and conglomerate found at the base of the Animikie farther west seem to be entirely lacking in the vicinity of Gunflint lake. This statement may need a few words of explanation. The name "Pewabic quartzyte" was proposed for, and applied to, the iron-bearing rocks of Akeley

*The lowest of these divisions corresponds to the "iron-bearing member," and the middle and upper divisions to the "upper slate member," of the geological map of Gunflint lake published by Irving and Van Hise; loc. cit.

†The Mesabi iron range: 20th Ann. Rept., p. 124, 1893.

‡The iron-bearing rocks of the western Mesabi range in Minnesota; Bull. No. 10, 1894.

lake.* Subsequently this term has been applied quite extensively to the quartzyte member at the base of the Animikie on the western Mesabi range, so that now the term Pewabic usually refers to this quartzyte, which, however, in the Minnesota reports has been considered as the equivalent of the iron-bearing rocks of Akeley lake. If the iron-bearing rocks of Akeley lake are thus put at the base of the Animikie, there seem to the writer to be serious objections to regarding them as the basal quartzyte and the equivalent of the quartzyte of the western Mesabi range. In the absence of anything like a conglomeratic base, in the intimate and rapid alternation of bands of siliceous and ferruginous material, and in other respects these rocks are closely analogous to certain parts of the iron-bearing member, and it is to this member that the writer would refer these rocks, if they belong to the Animikie. Moreover, in the Gunflint lake region no quartzyte has been found near the base of the Animikie and in several places the iron-bearing member has been seen lying directly upon the older crystalline rocks. Consequently it is stated that, so far as known, the basal quartzyte member is lacking in the vicinity of Gunflint lake.

As is stated above, the uppermost strata of the Animkie near Gunflint lake are fine grained quartzyte and quartz slates. This increase of coarser siliceous material in the higher beds of the Animikie is quite noticeable, and is also especially well shown in the vicinity of Pigeon point, north coast of lake Superior. At the latter place these quartzose beds (Wauswaugoning quartzyte) have been placed at the base of the Animikie in the recent Minnesota reports.† There seems, however, more reason for placing the Wauswaugoning quartzyte near the summit of this series than at its base, and for considering it as the probable equivalent of the quartzose beds at the top of the Animikie as exposed near Gunflint lake.

In the above estimates of the thickness of each member the diabase sills have been included. Their exact thickness is not known, but it is roughly estimated at not more than 75 feet for the lower, 100 feet for the middle, and 250 feet for the upper member. The following figures then will show the maximum thickness, in feet, of the Animikie at Gunflint lake, the estimate being based on an average dip of not more than 10 de-

*N. H. Winchell; 16th Ann. Rept., p. 86, 1888.

†See especially the "Table of Pre-Silurian Rocks," facing p. 4 of the 21st Ann. Rept.

grees, and on the assumption that there are no faults which would make the apparent thickness greater than the real:

	Sediments.	Diabase	Total.
The upper, or graywacke-slate, member...	1,650	250	1,900
The middle, or black slate, member.......	950	100	1,050
The lower, or iron-bearing, member.......	825	75	900
Total.............................	3,425	425	3,850

Igneous Rocks.

The igneous rocks of the Animikie, so far as seen by the writer, are all in the nature of intrusive sills or dikes; no surface eruptions have been recognized, nor has any evidence of contemporaneous volcanic activity been noted in the vicinity of Gunflint lake.* These sills are composed of diabase that varies much in grain, sometimes being very coarse in the center of the sills. They make up the characteristic ridges of the region and, as far as surface extent is concerned, cover perhaps a third of the area of the Animikie, although their aggregate thickness is much less than one third that of the whole series. The largest and most prominent sill is that forming the highest land between Loon and Gunflint lakes and along the south shore of South lake; it has a thickness of at least 100 feet.

The sills are not found to extend into the gabbro, nor have the two rocks been seen in contact. However, the gabbro is cut by a few dikes of diabase that might be referred to the same date as the sills. At the time of the gabbro intrusion the surrounding rocks were probably heated considerably, as the gabbro is not particularly finer grained at its contact with the country rocks; but in the case of the sills, even of the largest ones and those in closest proximity to the gabbro, both the upper and lower surfaces where seen are exceedingly fine grained. The relative ages of the two rocks are not definitely determined from the data thus far obtained about Gunflint lake.

IV. THE KEWEENAWAN.

Gabbro proper.

The great gabbro mass of this region was examined over a considerable extent of territory, This rock is found to vary somewhat in mineralogical composition, at times becoming, as at Little Saganaga lake, almost entirely composed of feldspar,

*This agrees well with the statement of Dr. A. C. Lawson concerning the absence of volcanic activity in the Animikie; Bulletin No. 8, p. 29, 1893. He proposes for these sills the term "Logan sills," Ibid., p. 48.

thus forming an anorthosyte petrographically similar to those described by Dr. A. C. Lawson from the north shore of lake Superior;* again it becomes exceedingly rich in olivine, this mineral sometimes making up half the rock mass.† The gabbro was found to include fragments of the Animikie slates, and it also was found directly overlying and in contact with beds of the upper member of the Animikie. This gives additional proof of the post-Animikie age of the gabbro.

Fine grained gabbro.

Associated with the coarse grained gabbro, or gabbro proper, and more frequently seen near its northern limit, are finer grained rocks which vary from gabbros and olivine gabbros to norytes and olivine norytes. To these rocks the term "muscovado"‡ has been applied. They are basic igneous rocks and are, as a rule, at least slightly older than the main mass of the gabbro, which is seen cutting and including fragments of them.

Acid eruptives.

In Ts. 62-6, 63-5, 63-4, 63-3 and in the southern edge of T. 64-2 are extensive exposures of reddish, hornblendic, granitic rocks. These make the highest hills of this region and these hills often form the water divide between the St. Lawrence and Hudson bay drainage. These rocks are undoubtedly part of what Prof. R. D. Irving termed the augite syenites of the Keweenawan,§ but as yet the writer has found no augite in them; however, in most specimens examined the original nature of the ferro-magnesian constituent cannot be determined. They probably represent deep-seated parts of the magmas that produced the extensive flows of rhyolytes, now largely aporhyolytes,‖ and other acid lavas seen about the Minnesota coast of lake Superior, especially at the Great Palisades and also at other points along this shore.

On approaching one of these areas of granitic rocks from the north a few small acid dikes are seen in the gabbro. These increase in frequency and size on coming nearer to the central

*Bulletin No. 8, 1893.

†For a description of the gabbro of Minnesota see article by Dr. W. S. Bayley, Jour. of Geol. vol 1, pp. 688-716, 1893.

‡See "Remarks on the so-called muscovadyte or muscovado rock," 21st Ann. Rept., pp. 143-153, 1893. Also Ibid., p. 30. 17th Ann. Rept., pp. 130-131.

§Copper-Bearing Rocks of Lake Superior, Mon. V, U. S. Geol. Survey, 1883.

‖For use of this term see article by Dr. Florence Bascom, Jour. of Geol., vol. 1, pp. 813-832, 1893.

mass of granite, and at the edge of this mass apophyses can be traced directly from the granite into the gabbro. This statement holds true for the relations of the gabbro and these granitic rocks as far as seen in the region here reported on. The dikes are not particularly finer grained, either as a whole or at their edges, than the granite of the main mass, thus indicating the heated condition of the gabbro when the dikes were intruded. From this and from the relation of these two rocks in other places it seems likely that the granite, while of a later date than the gabbro, still is not much younger and perhaps was intruded before the complete solidification of the basic rock.

V.

LIST OF ROCK SAMPLES COLLECTED IN 1893

BY U. S. GRANT.

CONTENTS.

An opportunity has not been offered for the study of these rocks since they were collected; consequently the names are to be regarded only as approximately correct. This list is a continuation of that ending on page 67 of the twenty-first annual report. The specimens in this series are numbered in green and can thus be distinguished from those of any other series of the survey or museum.

NORTH SHORE OF LAKE SUPERIOR.

894. Dark reddish, blotched amygdaloid. Point in S. W. ¼ S. W. ¼ sec. 33, 63–3 E.

895. Dark olivine diabase ("black trap"). Center of W. ½ W. ½ sec. 20, 62–4 E., Chicago (or Sickle) bay. Same as 1811 N. H. W.

TOWNSHIP 65 NORTH, RANGE 4 WEST.

896. Fine grained, gray gabbro. S. W. ¼ S. E. ¼ sec. 27, at the Y of the railroad.

897. White pegmatyte, from veins or dikes in the last.

898. Fine grained, gray gabbro, 2 inches from contact with slate. N. W. ¼ S. E. ¼ sec. 27, in railroad cut.

899. Coarse, gray gabbro, 2 feet from contact with slate.

900. Fine grained, micaceous schist (altered slate), 6 inches from contact with gabbro.

901. More micaceous facies of the last, 6 inches from contact with gabbro.

902. Fine grained diabase from dike in gabbro; the specimen shows one edge and about half the width of the dike. S. E. ¼ N. W. ¼ sec. 27, in railroad cut.

903. Small dikes of diabase, ¼ to 1½ inches wide, in greenstone. N. W. ¼ S. E. ¼ N. W. ¼ sec. 28, in railroad cut.

904. Impure, magnetitic quartzyte with films of hisingerite. S. W. ¼ N. E. ¼ sec. 29, 65–4, shaft 2, Akeley lake.

905. Graphitic rock. Same place.

906. Actinolitic rock holding pieces of quartz and a gray cherty rock. S. W. corner of N. W. ¼ N. W. ¼ sec. 27; from the "nickel" pit just S. of the wagon road.

907. Some of this gray cherty rock. Same place.

908. Fine grained, black, carbonaceous rock. Hill in the S. E. ¼ N. E. ¼ N. E. ¼ sec. 26, just south of the railroad.

909. Fine grained diabase. N. E. ¼ S. E. ¼ sec. 24, just north of the wagon road.

IRON REGIONS OF MICHIGAN.

910. Recomposed jasper of Upper Huronian. Millie mine. Iron Mountain.

911. Potsdam quartzyte showing quartz enlargements. Iron Mountain.

912. Lower Huronian magnetite-actinolite schist. Republic.

913. Lower Huronian quartzyte near base of this formation. Republic.

914. Quartzose pebble from basal conglomerate of the Lower Huronian. Republic.

915. Jaspery conglomerate at base of Upper Huronian. Goodrich mine, near Ispheming.

916. Impure quartzyte at base of Lower Huronian. Near Ishpheming.

917. Greenstone of the Basement Complex. Near Ispheming.

918. Carbonate rock of Lower Huronian. Near Ispheming.

919. Volcanic ash of Upper Huronian. Near Ironwood.

920. Cherty carbonate of the Upper Huronian. Palm mine. near Bessemer.

921. Carbonate changing to ore, Upper Huronian. Black river. east of Bessemer.

922. Granite of Basement complex. Near Bessemer.

923. Recomposed portion of the same forming a conglomerate that rests on the granite.

924. Chert with "bands and shots of ore." Colby mine, Bessemer.

DULUTH.

925 Very fine grained, black rock. Crossing of Piedmont and Lake avenues.

926. The same showing irregularly outlined, foreign pieces.

927. Same as the last.

928. The same with yellowish, vein-like forms.

TOWNSHIPS 64 AND 65 NORTH, RANGES 2, 3, 4, AND 5 WEST.

929. Coarse, vitreous quartzyte. N. E. ¼ N. E. ¼ sec. 34, 65-5.

930. Finely laminated magnetite and impure quartzyte. N. W. ¼ N. W. ¼ sec. 35, 65–5.

931. Coarse diabase (or gabbro) from center of sill. Portage in N. ½ N. W. ¼ sec. 35, 65-5.

931A. Finer diabase, 4 inches from top of same sill.

932. Diabase from center of dike in gabbro. Just north of the small island in N. E. ¼ S. E. ¼ sec. 34, 65-5, Kakigo (or Black Trout) lake.

933. Fine grained; gray gabbro. N. E. ¼ N. E. ¼ sec. 12, 64-5, Big Round lake.

933A. The same in contact with coarse gabbro.

934. Biotite granite from dike in gabbro. Near W. quarter post of sec. 7, 64-4, point in Big Round lake.

935. Fine grained, olivine gabbro. S. E. ¼ S. W. ¼ sec. 6, 64-4, Big Round lake.

936. Diabase from center of dike, 8 feet wide, in gabbro. S. E. ¼ S. W. ¼ sec. 8, 64–4, Big Round lake.

936A. Diabase and gabbro in contact. Same place.

936B. Film of diabase, ¼ inch wide, in gabbro. Same place.

937. Gabbro with a green stain. N. W. ¼ S. E. ¼ sec. 9, 64–4, north shore of Little Copper lake.

938. Fine grained, gray granite. Near west edge of S. W. ¼ S. W. ¼ sec. 16, 64–4.

939. Fine grained, olivine gabbro. N. W. corner of S. W. ¼ N. W. ¼ sec. 5, 64–4, south shore of small lake.

940. Slaty greenstone. A few rods south of the west quarter post of sec. 22, 65-4.

941. Gray syenite. West quarter post of sec. 22, 65-4.

941A. The same. Same place.

942. Grain syenite and greenstone in contact. N. ½ S. W. ¼ sec. 22, 65-4.

943. Magnetite iron ore from a bed 3 feet thick and about 110 feet below the surface. Shaft 1, S. E. ¼ N. E. ¼ sec. 28, 65-4.

944. Quartzyte, below gabbro sill. S. W. ¼ S. E. ¼ N. E. ¼ sec. 29, 65-4, within a few rods of Akeley lake.

945. Fine grained gabbro within six inches of bottom of sill. Same place.

946. Coarse gabbro from center of sill. Same place.

947. Quartzyte above gabbro sill. Same place.

948. Gabbro. S. W. ¼ N. E. ¼ sec. 29, 65-4, the most eastern island in Akeley lake.

949. Gabbro from sill in quartzyte. S. E. ½ N. E. ¼ sec, 28, 65-4, railroad cut.

950. Cherty carbonate. S. ½ N. W. ¼ N. E. ¼ sec. 24, 65-4.

950A. A rusted phase of the same.

951. Coarsely porphyritic diabase. S. E. ¼ N. W. ¼ sec. 19, 65-3, railroad cut just west of the narrows of Gunflint lake.

952. Diabase. Near south side of S. W. ¼ N. W. ¼ sec. 19, 65-3, railroad cut, north side of Animikie bay, Gunflint lake.

953. Contact of lower edge of diabase sill and slate. Near north side of N. E. ¼ S. E. ¼ sec. 24, 65-4, railroad cut at head of Animikie bay, Gunflint lake.

954. Flinty band in slate. Near same place.

955. Diabase. Near same place.

956. Calcareous deposit on face of cliff. S. W. ¼ N. E. ¼ sec. 24, 65-4, east end of large hill.

957. Conglomeratic portion of the slate. Same place, at foot of hill.

958. Breccia cemented by green amphibole. Same place, top of hill.

959. Peculiar markings on surface of slate. Same place, about half way up the hill.

960. Black, flinty slate. S. W. ¼ S. E. ¼ sec. 24, 65-4, cliff on south shore of Cross river.

960A. Another phase of these slates. Same place.

961. Black carbonaceous rock, scratched side is on line of contact between slate and this rock.

961A. Slate, scratched side is on line of same contact.

961B. Black carbonaceous rock, 30 inches above contact.

961C. Same, 15 feet above contact.

962. Black carbonaceous slate. Near center of N. ½ sec. 30, 65-3, south shore of Gunflint lake.

963. Black carbonaceous rock showing peculiar markings. Top of hill in N. W. ¼ N. E. ¼ sec. 25, 65-4.

964. Diabase from dike. N. W. ¼ N. E. ¼ sec. 25, 65-4.

965. Biotite gabbro. Near center of west side of S. W. ¼ sec. 25, 65-4.

965A. A phase of the same. Same place.

966. Gabbro. Near center of S. ½ sec. 25, 65-4.

967. Coarse grained diabase. 18 feet above contact with slate, top of cliff. S. E. ¼ N. E. ¼ sec. 29, 65-3.

967A. Fine grained diabase, 10 inches above contact.

967B. Fine grained diabase, 5 inches above contact.

967C. Fine grained diabase at contact; the side on the contact is scratched.

967D. Slate at contact.

967E. Slate.

967F. Slate. The upper surface of these specimens of slate are scratched; these pieces were in contact with each other.

968. Hard siliceous slate. Near east edge of N. E. ¼ S. E ¼ sec. 25, 65-4, 100 yards S. W. of the road.

969. Slate, 15 feet below contact with gabbro. Near center of S. E. ¼ sec. 25, 65-4.

969A. Slate, 4 feet below contact.

969B. Slate, 3 feet below contact.

969C. Contact of slate and gabbro.

969D. Gabbro, 1 foot above contact.

969E. Gabbro, 25 feet above contact.

970. Spotted, black, carbonaceous slate. S. E. ¼ S. W. ¼ sec. 29, 65-3, north or lower cliff of Prospect mount.

971. Gray, cherty rock from bed 9 inches in thickness. Same place.

972. Slate spotted with small white crystals. S. E. ¼ S. W. ¼ sec. 29, 65-3, main cliff of Prospect mount.

973. Fine grained black rock with small blotches. Same place.

974. Black slate, one-half inch from lower surface of diabase sill. Same place.

974A. More fissile slate, 10 inches below sill.

975. Coarse grained diabase. N. E. ¼ N. W. ¼ sec. 32, 65-3, top of Prospect mount.

976. Gabbro? N. E. ¼ N. E. ¼ sec. 31, 65-3.

977. Coarse grained porphyritic diabase. Sec. 27, 65-3, north shore of Loon lake.

977A. Coarse grained diabase, not porphyritic. Same place.

978. Fine grained siliceous slate. S. W. ¼ N. E. ¼ sec. 32, 65-3, southwest corner of Loon lake.

979. Gabbro. Top of ridge at same place.

980. Fine grained, gray quartzyte. Near center of N. ½ sec. 35, 65-3, north shore of point in Loon lake.

980A. Same, banded with black slate. Same place.

981. Spotted black slate. West line of sec. 27, 65-3, a short distance north of the quarter post.

982. Dark siliceous slate, one inch below diabase sill. S. E. ¼ N. W. ¼ sec. 35, 65-3, hill on point in Loon lake.

983. Gabbro. Near center of E. ½ sec. 32, 65-3, near southwest corner of Loon lake.

983A. Fine grained, biotitic rock. Near same place.

983B. Siliceous slate. Near same place.

984. Fine grained, reddish weathering, gray quartzyte. N. ½ N. E. ¼ S. E. ¼ sec. 32, 65-3, near southwest end of Loon lake.

985. Gabbro? A few rods south of the last.

986. Gabbro? West line of sec. 34, 65-3, one-fourth mile south of Loon lake.

987. Mottled dioryte. N. W. ¼ S. E. ¼ sec. 34, 65-3, on road.

988. Gabbro. N. W. ¼ S. E. ¼ sec. 35, 65-3. Between road and Loon lake.

989. Olivine gabbro interbanded with coarser gabbro. S. W. ¼ N. W. ¼ sec. 11, 64-3.

989A. Coarser gabbro. Same place.

990. Gabbro. S. W. ¼ sec. 11, 64-3, south shore of lake.

991. Gabbro. S. E. ¼ N. E. ¼ sec. 11, 64-2, Poplar lake.

992. Diabase. N. E. ¼ N. W. ¼ sec. 34, 65-2, top of hill at east end of lake Emma.

992A. Fine grained, porphyritic diabase. North side of same hill.

993. Micaceous schist. N. W. ¼ N. E. ¼ sec. 34, 65-2, portage between No-Name lake and lake Emma.

994. Diabase. West line of sec. 36, 65-2, 500 feet south of No-Name lake.

995. Coarse grained, gray diabase. N. E. ¼ S. E. ¼ sec. 35, 65-2, north shore of No-Name lake.

996. Fine grained, gray quartzyte, scratched side was one-quarter inch below diabase sill. Near center of sec. 27, 65-2.

996A. The same, 13 inches below diabase sill.

997. Diabase. N. E. ¼ S. W. ¼ sec. 22, 65-2, north shore of South lake, just west of the International Boundary portage.

997A. A phase of the same. Same place.

998. Fissile, black, carbonaceous slate. S. W. ¼ S. E. ¼ sec. 21, 65-2, west end of South lake.

999. Fine grained diabase showing effects of weathering. N. W. ¼ N. W. ¼ sec. 25, 65-2, portage leading south from South lake.

1000. Breccia of black slate. A short distance north of the S. E. corner of sec. 24, 65-2, south of South lake.

1001. Diabase. W. ½ sec. 22, 65-2, portage between North and South lakes.

1002. Cherty carbonate with rusty-weathering areas; not in place. Sec. 21, 65-2, North lake.

1003. Jasper. Near center of N. E. ¼ sec. 16, 65-2 south shore of narrow arm of North lake.

1003A. Jasper with green and red granules. Same place.

1003B. Gray rock with granules, associated with the jasper. Same place.

1004. Fragments of red jasper, with granules, from the beach; not in place. South shore of North lake just east of the portage to South lake.

1005. Green rock with granules. Pits in N. W. ¼ S. W. ¼ sec. 16, 65-2.

1005A. A more flinty phase of the same.

1005B. A rusted phase of the same.

1005C. Black flinty rock.

1005D. Finely banded jasper and magnetite.

1005E. Magnetite iron ore.

Railroad on north side of Gunflint lake.

1006. Flint. A short distance west of the rapids between North and Gunflint lakes. Nos. 1006 to 1007C belong to the Animikie.

1007. Contact of diabase and flint.

1007A. Gray branded flint.

1007B. Finely banded jasper.

1007C. Cherty carbonate, changing to limonite.

1008. Sheared quartz porphyry. Nos. 1008 to 1008C belong to the Keewatin.

1008A. The same showing weathered surface.

1008B. The same showing contact with a non-porphyritic rock.

1008C. Argillyte.

ELY AND TOWER.

1009. Altered diabase. Ely.

1010. Coarse quartzose rock. South of Stuntz bay, Vermilion lake.

1011. Matrix of conglomerate. Just south of western side of Stuntz bay, Vermilion lake.

1011A. Pebbles from the same.

1012. Sericitic schist with quartz grains. Ely island, Vermilion lake.

1013. More massive form of the same. Same place.

1014. Augite porphyryte ?, showing one-half the width of a dike. Same place.

1014. The same, from a point where the dike was 3 feet wide; center of dike.

1015. Greenstone. Just south of Tower.

1016. Jasper with fine white veins. Tower.

VI.

LIST OF ROCK SAMPLES COLLECTED IN 1893*

BY A. D. MEEDS.

These samples were collected in ranges 12 to 15 (inclusive) west of the Fourth principal meridian, and between lake Superior and the Vermilion iron range. No examination in the laboratory has been made of these rocks, so the designations are only approximately correct. Rocks of this series are numbered in white, each number followed by the letter M, to distinguish them from the other series of the survey and museum.

1. Medium grained gabbro. E. line of sec. 36, 61–12.

2. Very fine grained gabbro, with black lines. E. line of sec. 3, 60–12.

2a. Crystallized quartzyte. Same place.

2b. Same as No. 2. Same place.

3. Red, hornblende granite. Center of N. ½ sec. 10, 61–13; north shore of Stuntz lake.

4. Gray, hornblende granite. Near S. E. corner sec. 15, 61-13; south shore of Stuntz lake.

4a. Phase of the same. Same place.

4b. Granite. Same place.

4c. Pinkish granite. Same place.

4d. Very fine grained, gray granite. Same place.

5. Rather fine grained, olivine gabbro. W. line of sec. 25, 61–12, near quarter post.

6. Fine grained, olivine gabbro. N. E. ¼ S. W. ¼ sec. 10, 60-12; end of portage on Dunka river.

*This list was prepared from Mr. Meeds' specimens and note books by Dr. U. S. Grant.

7. Fine grained, magnetic quartzyte. W. line of sec. 17, 60–12.

7a. The same showing pitted, weathered surface. Same place.

8. Mica schist. S. E. ¼ S. E. ¼ sec. 35, 60–13.

9. Coarse grained gabbro. N. W. ¼ N. W. ¼ sec. 6, 59-12.

10. Magnetic iron ore. W. side of N. W. ¼ N. W. ¼ sec. 14, 59–14.

11. Phase of the same. Same place.

12. Hard hematite. N. E. ¼ sec. 11, 59–14; Mallmann mine.

13. Hard hematite. Sec. 18, 59–14; Stone shaft.

14. Impure hematite. Near same place.

15. Quartzyte. Aurora pit; probably in S. E. ¼ N. E. ¼ sec. 24, 59–15. (Missing).

16. Fine grained quartzyte. Near N. line of sec 24, 59-15.

17. Pinkish gabbro from boulder. Sec. 24, 58-12; island in Seven Beaver lake.

18. Gabbro. S. W. ¼ S. E. ¼ sec. 31, 54–13.

18a. The same with magnetite. Same place.

19. Olivine gabbro. N. W. ¼ N. W. ¼ sec. 15, 54-13; end of portage on Cloquet river.

19a. Phase of the same with much olivine. Same place.

19b. Phase of the same. Same place.

19c. Rough-weathering phase of the same. Same place.

20. Olivine gabbro. Near north edge of N. W. ¼ sec. 15, 54–13; middle of portage along Cloquet river.

21. Fine grained, micaceous quartzyte. Sec. 18, 59–14; Stone mine.

22. Jaspery conglomerate. Same place.

23. Micaceous slate. Same place.

24. Limonitic shale. Same place, top of shaft.

25. Magnetic taconyte. Below last.

26. Dark, slaty taconyte. Same place.

27. Jasper. Bottom of shaft.

27a. Purplish taconyte. Bottom of shaft.

28. Siliceous shale. N. E. of shaft.

29. Hornblende granite. Near Hinsdale.

30. Fine grained diabase from dike. N. edge of N. E. ¼ N. E. ¼ sec. 24, 55-12.

30a. Quartzless porphyry. Same place.

31. Gabbro near dike. Same place.

32. Reddish, mottled dioryte. Same place.

33. Contact of diabase and gabbro. Same place.

34. Mottled dioryte from another dike. E. edge of N. E. ¼ S. E. ¼ sec. 24, 55-12.

35. Olivine gabbro from boulder. N. W. ¼ sec. 24, 55-12.

36. Fine grained, red syenite. W. line of sec. 23, 53-12; in creek bed.

37. Fine grained, red syenite. S. line of sec. 36, 53-12.

37a. Phase of the same. Same place.

38. Fine grained, red syenite, not in place. Near Highland.

39. Dioryte. N. W. ¼ N. W. ¼ sec. 34, 53-12.

40. Coarse grained, olivine gabbro. N. line of sec. 5, 54-13.

41. Coarse grained gabbro from boulder. A little west of the last.

42. Coarse grained gabbro. N. E. ¼ N. E. ¼ sec. 30, 53-14; southeast shore of Boulder lake.

43. Coarse grained gabbro with long, slender feldspar crystals. N. E. ¼ sec. 18, 53-13; falls in Cloquet river.

44. Anorthosyte from boulder. S. E. ¼ S. E. ¼ sec. 19, 53-13; dam in Cloquet river.

44a. Phase of the same with darker areas. Same place.

45. Coarse grained gabbro. N. E. ¼ sec. 36, 53-14; rapids in Cloquet river.

46. Olivine gabbro. S. E. ¼ sec. 35, 53-14; falls in Cloquet river.

VII.

PRELIMINARY REPORT OF A RECONNOISSANCE IN NORTHWESTERN MINNESOTA DURING 1893.

BY J. E. TODD.

ITINERARY.

Having been met by my assistant, Mr. H. B. Hovland, at Minneapolis, we left that city June 22d for Thief River Falls. At that place I engaged Mr. J. C. O'Brien, an experienced "cruiser," to accompany us on a trip on foot through the northern parts of the Red Lake Indian Reservation, completed my outfit, and engaged an experienced hunter to take us with his team to an old hunting camp about thirty miles northeast of Thief River Falls. My purpose was to keep a northeast course, if possible, till we struck the survey of the Duluth and Winnipeg railroad, and then to explore the so-called "Beltrami island of lake Agassiz."*

We left Thief River Falls June 26th, and Cook's shanties in N. W. ¼ of sec. 19, T. 156, R. 39 (the before mentioned hunter's camp) on the morning of the 28th. We kept a northeast course as nearly as was practicable in trackless swamps and for many miles through wind-falls where we did well if we advanced five miles a day. Besides, we lost some time on account of rain. Failing to find the railroad survey, probably because its trace was obliterated by fire, we kept our course till we struck the Rainy river about five miles above its mouth, July 12th. Having there built a raft, we descended the stream till we found settlers. At Hungry Hall we bought a new birch canoe and proceeded to the Lake of the Woods and along its southern shore to Long point. Thence we retraced our course, going

*Warren Upham, in American Geologist, vol. xi, pp. 423-425, June, 1893.

up the Rainy river to Pinewoods P. O., where we took the steamer "Shamrock" to the mouth of the Big fork, proposing to ascend it and the Sturgeon river,* its main western branch, to a portage into the Tamarack river, which we should descend and then cross Red lake to the Red Lake Agency. Owing to misinformation, we ascended the wrong one of the numerous branches of the Sturgeon river, and somewhat rashly abandoned our canoe not far from the northwest corner of T. 154, R. 27. Taking our packs, we traveled southwest and west to the south branch of Tamarack river, made a raft but found the stream closed by the work of beavers, and then, striking a recent land survey near the southwest corner of sec. 24, T. 154, R. 29, we followed it due west from there to Red lake a little south of the mouth of the Tamarack river. We arrived at the Indian village at "the Narrows" the morning of August 3d, hired a canoe, and reached Red Lake Agency late August 4th. Here Mr. O'Brien left us, we bought another canoe, and hired an Indian to take us and our outfit in a wagon to the head of Turtle lake, the spot which Beltrami considered the hydrographical center of the continent. We were landed at this point about noon, August 8th.

We proceeded down Turtle river (making two long portages above Turtle River lake) to Cass lake, and thence went up the Mississippi to lake Bemidji, arriving the 16th. Thence we went south up the Schoolcraft river to sec. 3, T. 144, R. 34, where I obtained a fine view of a wide region from the top of a high spruce, and then returned to Bemidji. There we left our canoe and engaged passage with a settler going by Bagley's dam and How's to Fosston, where we took the cars on the 22d, Mr. Hovland for Minneapolis, and I for Park Rapids, via Sauk Center.

From Park Rapids I took a trip along the new railroad grade to Akeley and on northeast and north into the moraine north of Eleventh lake (the head of the Crow Wing river), to sec. 10, T. 142, R. 32. From Park Rapids I returned to Sauk Center, then took a flying trip up to Northcote, availing myself of the courtesy of the Great Northern railway company to see the country in western Marshall and Kittson counties. I arrived at Minneapolis August 29th.

I met many intelligent woodsmen and Indians at various times who gave me numerous valuable facts regarding the re-

*Called Opimabonowin river by Horace V. Winchell, Sixteenth Annual Report, p. 431.

gion I have been studying, thus supplementing to no inconsiderable degree our personal observations.

SUMMARY OF PRINCIPAL RESULTS.

The more important results of our summer's work may be enumerated as follows:

1. The whole area traversed till we reached Red lake was shaped by lacustrine action. Though I had confidently expected to find areas untouched by it, and having the common glacial topography, I visited none which did not show, wherever above the marsh, sandy ridges which were evidently beaches. The highest point found was an abrupt ridge rising about 40 feet above the swamp surrounding it. I have little doubt that it was crossed by the Duluth and Winnipeg railroad survey before spoken of. It was about in line with it and almost the only area which was completely burned off, and that quite recently. The ridge was quite bouldery, about a mile long, trending northeastward, and seemed to have been a bar detached from land. We saw higher land a few miles west, but there was a wet swamp between and we at that time hoped to find the railroad survey farther on and follow it. I judge that much of the region traversed between Cook's shanties and the Rainy river was considerably higher than those points, because old beaver dams abounded at both ends of that trip. Much of the country between those points was tamarack, spruce, and cedar swamps; but toward Rainy river, especially, low sand ridges 1 to 5 feet high abounded. Among these ridges it was noticed that the swamps were wetter adjoining the south side of each ridge, which was accounted for by supposing a gentle descent toward the north. The only stream crossed, which was at a distance of about fifteen miles southwest of the Rainy river, had a width of about twelve feet and a depth of two feet, with a strong current southeastward. It is probably a branch of the Rapid river.

In our course to Rainy river, we found the marsh, though almost continuous, yet not very deep, except about Mud lake, which is in Ts. 156, Rs. 41 and 42, where there are extensive grassy quagmires and south of a small lake said to be the head of the east branch of Roseau river in or near the southwest corner of T. 159, R. 33, where a "muskeg" covers several square miles. Elsewhere there seemed to be firm sand 2 to 4 feet below the surface of the moss. We tested it at several

points. Large boulders not infrequently rose above the moss, even in open swamps. On our return from Rainy river, we did not have the opportunity, while in the canoe, of noting the country; but from examination at several points, and by the trees and the frequent rills trickling into the streams, we judged that the same shallow sphagnum swamp prevailed. Along the lower course of the Tamarack river, east of the north part of Red lake, we found alder swamps which presented more serious hindrance, with deep muddy bog holes. These were probably connected with the work of beavers.

We found prairie covering most of the region from Thief River Falls to Cook's shanties, and in patches to the northeast corner of T. 156, R. 38, also a considerable area 10 or 12 miles from Rainy river, where a swamp had been burned out and prairie grass had become the main covering, with here and there willow patches around the nearly consumed remains of cedars. The soil was rich, the ground mostly firm, the subsoil a bouldery clay. This suggests that most of this region may be similarly reclaimed. No very large patches of white or red pine were observed.

2. Of the higher region, named by Mr. Upham "Beltrami island," we learned some facts from different hunters. We attempted to sift their stories. The higher portion of it is said to lie between the head of the War Road river and the East Roseau, I judge not far east of the southeast corner of Kittson county. The ridges are higher toward the south and rise "20 feet or more above the swamps between." They trend N. E.-S. W. and are covered with pines. One ridge is five miles wide. No lakes were noticed except in a big swamp eight or nine miles long and two miles broad, north of the higher ridges. The railroad survey runs across this swamp on a strip which bears tamarack.

3. From Red lake southeast, the country rises quite rapidly to the level of a plateau which lies on the divide between the Red lake region and the Mississippi. It is estimated to be, in its highest portions, about 300 feet above Red lake. It is largely covered with clayey poplar flats, with groves of pine and hard maples interspersed. It abounds in lakes and has few elevations except in connection with the moraines hereafter to be enumerated. The watershed is not clearly defined. Former glacial stream channels cross it in several places.

4. Several moraines were crossed in our course.

(*a*). That which divides the two portions of Red lake. We have no important notes to add to those already published. We hoped to find trace of its extension to the west, but failed to discover anything decisive. Probably the higher portion of "Beltrami island" and the ridge between Jadis and the War Road river are to be correlated with it, the intermediate portions of this moraine having been levelled by the waters of lake Agassiz as they were dropped from the ice-sheet or at a later stage. We were unable also to establish the extension of this ridge much to the east of Red lake.

(*b*). Between Red Lake Agency and Cass lake we crossed four well defined moraines, with a less prominent one between the two pairs in which the four might easily be grouped. The first, counting from the north, we crossed two to four miles from Red Lake. It lay along the upper part of a rather abrupt rise from the level of the Agency. Its higher portion rose about 150 feet above the lake. It presented in fine form the usual basins and knobs, but the latter were of more even hight than common and corresponded approximately with the level of the plain just south. This corresponds, without much doubt, to the moraine noted last year north of Clearwater lake, running east across Sandy river, and perhaps to one east of Fosston, trending south.*

(*c*). After crossing a quite level clayey strip, we came to the second moraine, marking another slope and presenting similar features to the last, about eight miles from the lake and reaching up to 225 or 250 feet above it. This corresponds to the moraine crossed last year south of Clearwater lake, and this year east of Popple, or about "15 miles east of Fosston." There it is trending south.

(*d*). About two miles north of the northwest corner of T. 148, R. 33, we crossed low ridges rising 10 to 20 feet above the surrounding clayey plain, as though nearly submerged in it. They trended north of east. Scattering ones a little farther north were also noticed. These seem to correlate with a strip near the Buzzle lakes, crossed east of Bagley dam, which is on sec. 31, T. 148, R. 35, perhaps also corresponding to hills west of Spain's and to some east of Upper Rice lake, which is on the west side of T. 145, R. 36.

(*e*). Another well developed moraine was found running east and west along the north line of Ts. 147, Rs, 32 and 33, south of Turtle River lake and Turtle lakes. Some hills rose

*Twenty-first Annual Report, pp. 72, 73.

60 feet or so above the lakes. This corresponds to the morainic belt crossed last year, and again this year, in the north part of T. 147, R. 35. It curves southwest and south, crossing Grant creek near the southwest corner of the same township, and running southwest of the Schoolcraft river into Hubbard county. Some of its inner knobs lie along the west side of lake Marquette and rise 75 feet above it. It has a still higher ridge southwest of lake Plantagenet. It seems, according to reports of woodmen, to correlate with a strip passing Elbow lake, east of Park Rapids, and said to continue on southeast to Pillager.

(*f*). Another well developed moraine was crossed north of the lake next north of Cass lake; i. e. on the southeast corner of T. 147, R. 31; also, where the Mississippi flows southward east of lake Bemidji. Thence it curves more south, passing east of Schoolcraft river, and between lakes Sheridan and Kabekona, thence southeast, south of the latter, and on eastward south of Leech lake, where, as I reported last year, I believe that it forms a re-entrant angle and then runs southward west of Pine lake and on to the western one of the morainic strips south of Gull lake.

These correlations are of course provisional. The conception which was suggested last year seems to be corroborated by the observations of this. Its main features are that two lobes of the ice-sheet, one occupying the Red lake region, the other the basin of lake Superior, were at first confluent, but afterward becoming reduced first deposited the moraine (*d*); that, later, the former of these ice-lobes accumulated the moraine (*c*) on its south margin, and the other (*e*) on its northwestern margin. Still later they similarly formed, respectively, (*b*) and (*f*), each contemporaneous pair of moraines being farther apart toward the southwest and probably forming a sharp re-entrant angle or interlobate moraine toward the northeast.

5. Exposures of bed-rock are comparatively rare. Those observed may be enumerated as follows:

(*a*). On the south shore of the Lake of the Woods three granite points run out into the lake. The first on the west, named Rocky point, was visited last year. The second and longest is called Long point, the west side of which trends N. 20° W. (mag.) and consists mostly of gneiss which dips sharply to the northeast. The rock rises about 20 feet above the lake. Stony point, a short point about a mile east of the last, is faced with

gneiss for several rods, and is said to have, about a quarter of a mile from the shore, a rocky knob rising some 50 feet above the surrounding country. We did not explore it on account of rain. Several rocky islets appear off these points.

(*b*). At Zipple's fishery, near the mouth of Sand creek, is a low knob of dark magnetic "gabbro", and about half a mile west is an extensive mound of a similar rock rising 40 feet above the lake. These rocks were all evidently shaped by land ice, though glacial striæ were not common. The few noted were east of south.

(*c*). No other outcrops were found till we reached Rapid river. A few rods above its junction with Rainy river, it falls over a high ledge of black siliceous schist or slate. The rock rises about 30 feet above the Rainy river, and the falls are perhaps 20 feet high. A ledge of magnetic "gabbro" with granite juts out on the American side at water level about a half mile east of Rapid river.

Having glanced over Dr. Lawson's report on the Rainy river region to the Canadian government, and Mr. H. V. Winchell's account in the Sixteenth Annual Report of the Minn. Geol. Survey, I forbear saying anything further about other rock exposures on the Rainy river and the Big fork.

No ledges of Paleozoic rocks were found. In the bed of a rapid near the center of sec. 28, T. 148, R. 32, on Turtle river just above Turtle River lake, I found the bottom of the stream covered over several square yards with limestone pebbles and calcareous mud, but found no rock in position. Mr. Joseph Sombs of Park Rapids, who has spent some time "cruising" and also on a claim in T. 150, R. 31, says that on the south side of Black Duck lake there is much limestone along the stream for six or seven miles, that the masses of stone are not worn, and that the south bank is "50 to 60 feet high."

Black Duck river is represented by several from that region as the main stream running into Red lake. Mr. O'Brien states that, when Red lake first freezes in the fall, there is left a narrow strip of open water reaching from the mouth of Black Duck river across the south part of the lake to the outlet, Red Lake river, which remains open considerably longer than the rest. I regret that time did not allow me to ascend the east branch of Turtle river and go over to the head of Black Duck river and examine what is spoken of as one of the most promising tracts for agriculture in that part of the state.

VIII.

NOTES ON THE GEOLOGY OF ITASCA COUNTY, MINNESOTA.

BY G. E. CULVER.

CONTENTS.

INTRODUCTION.

The field season of 1893 was spent by the writer in an examination of portions of Itasca county. Mr. H. C. Carel of the University of Minnesota acted as topographer.

The plan of the work included a somewhat careful survey of two special areas which had been selected by the State Geologist for more detailed study, together with as thorough a reconnoissance of the remainder of the county as circumstances would permit. Particular attention was to be given to the

region between the Big fork and the Little fork of Rainy river.

The special areas covered the part of the Mesabi range lying in Itasca county, and included about three hundred square miles. The topography was indicated by fifty foot contour lines drawn on the township plats.

When the work on these areas was completed, the region lying immediately north was examined. The line of travel was through Wabano, Trout, Spider and Ruby lakes to the watershed between the Mississippi river and Hudson bay, which was crossed in T. 59–25. The region about the headwaters of Prairie river was inaccessible on account of the obstruction of Prairie river by logs. Accordingly the trip down the Big fork or Bowstring river was next undertaken. It was expected that the return trip would be made by the Little fork, but the water was found to be so low that this route had to be abandoned and the home trip made by way of Rainy lake, Black bay, Kabetogama and Namekan lakes, and the Vermilion river.

The weather was exceedingly favorable for field work during the summer. The low stage of water in the rivers was a hindrance to travel, compensated for somewhat by the better exposure of some rock outcrops.

The whole county is so deeply drift-covered, in all but the northeast portion, that rock exposures are few and far between. Days and weeks of tramping through the dense brush in search of outcrops were rewarded only rarely by finding them.

The Big fork and Little fork had been traversed in 1887 by Mr. H. V. Winchell, and although he made a very rapid journey, he gathered a great amount of information and made many valuable observations, besides collecting a number of rock specimens. His notes* were of much advantage to me.

TOPOGRAPHY.

In all the southern and central parts of the county, so far as I saw it, the topographic features are very largely due to the action of the great ice-sheet.

Before the advent of the ice the region was probably a level one, comparatively speaking. There were here and there ridges, which still remain; there were also valleys, which may have been deeper than the present ones, as the hills were, no doubt, higher, so that a somewhat stronger relief prevailed then than now.

*Geol. and Nat. Hist. Survey of Minn., 16th Ann. Rept., for 1887, pp. 395-478, with map.

That the ice covered the region for a very long time is a necessary result of its great southward extension. Nevertheless it seems to have changed the topography rather more by filling than by local erosion. Of this the thick mantle of drift is evidence. The character of the rocks may account for this fact, but the ridges of soft Cretaceous rocks seem also to have withstood the action of the ice.

On its retreat the ice seems to have given up its occupancy with considerable reluctance. The disposition of morainic accumulations indicates many halts in the final retreat.

In the immediate valley of the Mississippi a considerable belt of stratified drift occurs. It forms irregular terraces, which are rarely true river terraces, being sand plains formed by the wash from adjacent moraines. The belt of this material varies from one to five or more miles in width. In the wide places the plains often slope steadily down to swamps.

Plains of a similar character are found in the valley of Prairie river and its tributaries. A good example is found in the region of Wabano and Trout lakes. The east half of T. 57-25 and the east two-thirds of T. 58-25 are occupied by a practically continuous plain, separated by the lakes named from a moraine running roughly parallel with the plain. In both these townships, but particularly in T. 58-25, numerous lakes are sunk deep below the level of the plain. These lie nearly at the same level, so that while the surface of the plain rises to the north the water level in the lakes is maintained and their surfaces are found to be steadily farther below the surface of the plain as we go north. In the southern part of the plain they are from forty to fifty feet below the plain, and in the northern part eighty to ninety feet below. Many of them have no outlets.

The large lakes, Trout and Wabano, as well as half a dozen smaller ones, form a chain extending from the water shed in T. 59-25 to Prairie river. This chain of lakes marks the position of an old drainage line or valley in the expansions of which the lakes now lie. The plain just noted lies immediately to the east and rises from fifty to ninety feet above the water. A moraine lies close along the west side of the valley.

It will be seen that the water in the chain of lakes lies very nearly at the same level as that of the lakes which are sunk in the plain.

The valley is narrow and somewhat gorge-like between Trout and Ruby lakes in T. 58-25, a distance of a mile and a half. Its

width in this portion is a quarter of a mile and it is ninety feet deep. The eastern side is steep.

In all the rest of the upper part of the valley it appears to be mature. Clearwater creek, which connects Wabano lake with Prairie river, is a postglacial stream. The old valley was filled by the stratified drift below Wabano lake.

I.—LAKES AND SWAMPS.

Knobs and kettles are abundant in this part of the county. The depressions are sometimes dry "kettles," but more often by far they are either swamps or lakes, both of which are almost innumerable and of sizes varying from a few rods across up to lakes several miles in diameter and swamps which cover a township.

II.—PREGLACIAL RIDGES (CRETACEOUS).

Rising above the morainic accumulations in some places are various hills and ridges, some flat-topped, more oval, and others narrow and elongated. The morainic hills are almost always sandy. These hills are always clayey. Very few boulders are seen and the coat of blue clay till is very thin. The timber on these ridges is nearly always maple, while that on the other hills consists of birch and other soft wood.

The largest of these ridges is found in the southern part of T. 54-26, southwest of Pokegama. lake. It is a long and rather narrow ridge with northeast by east trend and rises three hundred feet above Pokegama lake. Its north flank is covered by heavy morainic accumulations, which do not however reach its summit. They abound in kettles and irregular depressions often seventy-five feet and sometimes more than one hundred feet in depth.

Another hill oval in shape rises one hundred and fifty feet above Pokegama lake in sections 22 and 23, T. 55-26. It is like the ridge just noted in all but shape and elevation and like it is flanked on its north side by a moraine.

From the fact that these hills, of which these two are types, are apparently of blue clay at the surface, and from the further fact that in shallow cuts, made in grading logging roads, I found what I think was Cretaceous shale in small fragments only, I am of opinion that they will prove to be Cretaceous outliers which have withstood the gnawing of the streams and the grinding of the ice and yet endure to mark the former eastward extension of the great Cretaceous sea.

Viewing the topography of the district as a whole, it is seen to be almost entirely recent in origin. Drainage is not yet fully established. There has been very little postglacial erosion. The precipitated moisture collects in the numberless swamps and lakes and there remains. The supply is only a little more than the demands of evaporation and the needs of the abundant vegetation. The large lakes have outlets, but they constitute the exception.

The northern part of the county is apparently quite level, especially towards the west. However, less was seen of this portion and it may be that there are topographic features here not now known, which will appear when the timber is cleared away.

It is not improbable that the suggestion made by Mr. H. V. Winchell, that this region lies in that covered by lake Agassiz, will prove to be correct. Still no important evidence pro or con, was collected by the writer. Careful watch was kept for indications of old shore lines and beaches, but none were seen. Sections along the river did not show beds which could be attributed to any but river or ice action. Through T. 61-25 and T. 62-25 moraines were noted crossing the river. Beds of sand washed down from these moraines are common, but elsewhere only clay was seen along this stream (Big fork). The banks of the Little fork are of the same nature, so far as they were seen by me.

III.—ROCK BASIN DISTRICT.

The topography of the northeastern part of the county is, in many respects, quite different and constitutes a distinct district. Going up Rainy river, we pass, at the Koochiching falls, somewhat abruptly from a region so deeply drift-covered that rock is seen only in the beds of the streams, to one in which drift is seen only in depressions in the uneven rock surface or along the beaches of the lakes. Rock bosses, ridges and knobs are everywhere, but they seldom rise more than twenty or thirty feet above the lakes, until the region about the mouth of the Vermilion is reached. There the rock masses rise to perhaps one hundred and fifty feet in some cases. Till is scarce until after the mouth of the Pelican is passed, going up Vermilion river; at that point the drift begins to thicken again.

The county is thus seen to be separated into three well marked topographical districts. Roughly speaking, the south two-thirds of the county constitute the first district. Its topography

is mainly morainic. The west two-thirds of the remainder of the county is an alluvial or lacustrine plain, while the north-east corner belongs in the district of bare rocky basins and rocky prominences.

ROCK SYSTEMS OBSERVED.

I. POKEGAMA QUARTZYTE (PEWABIC).

The first rock examined was the quartzyte at Pokegama falls, on the Mississippi.

This rock appears at intervals along an irregular line extending from the north end of Pokegama lake, in the S. W. ¼ of the N. E. ¼ of sec. 23, northeasterly to the rapids of Prairie river. Test pits show the continuation of this rock as far east as the east line of T. 56–24, where it passes out of my district. It is not known to outcrop east of Prairie river, and is only seen in a few places between the rapids of that stream and Pokegama falls.

It is a flat lying rock with a low southerly and southeasterly dip, and seems to have been bowed up into a series of low flat arches. This feature is more noticeable in the large exposures near Prairie river.

At all exposures the rock appears pinkish, is rather fine grained and very hard. At Pokegama falls, where it has been quarried to some extent, the rock is seen to have been originally greenish in color. The reddish coloration is due to causes external to the rock itself. The coloration has penetrated from the surface and from all fissures and joints toward the center of the cubical blocks into which the joint-planes divide it. In some cases the blocks are small enough so that the change from green to red is complete; in others a greenish core is surrounded by a pinkish shell, which varies from one to four inches in thickness. Cross sections of these blocks (figure 1) show that the change proceeded from all sides.

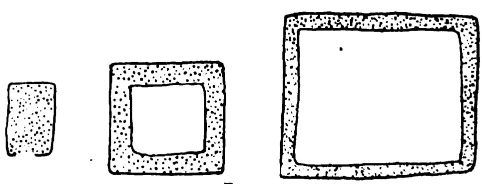


FIG. 1—Sections of quartzyte blocks, showing mode of change in color; outside pinkish, greenish within. Pokegama falls.

Some of the more massive beds toward the base of the section are very little changed in color. This is well seen in the bed of the Prairie river, a little above the bridge in the S. E. ¼ of sec. 34, T. 56-25, and also at the quarry above Pokegama falls.

Besides the red coloration, considerable iron ore is found in the quartzyte at many places, apparently always in the upper portion of the series. The character of these upper, ore-bearing strata is decidedly different from that of the lower beds. The ore-bearing rock, when seen in cross section, presents an irregularly banded appearance; the layers are alternately sheets of ore and sheets of quartz. As seen under the hand lens, the quartz layers show no grains; the structure is porous, and the quartz is usually stained red. The ore sheets vary from ferruginous quartz to a very good ore. Both ore sheets and quartz layers are exceedingly irregular and are often interrupted or cut by each other.

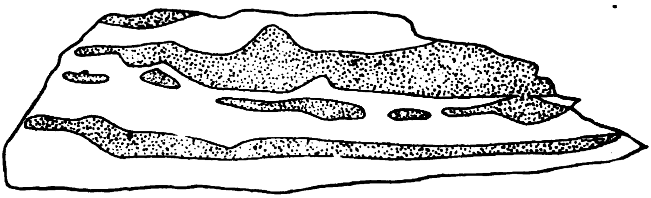


Fig. 2.—Hand specimen of ore-bearing rock, T. 56-24; showing the irregular banding seen in cross sections. The dotted areas are quartz, the others lean ore.

This irregularity is far greater than any that could have been produced by the slight movements which have affected the containing beds, and evidently it dates from the formation of the ore, whether that was contemporaneous with the formation of the containing beds or not.

The study of a large number of thin sections of this rock is necessary to determine the genesis, both of the ore and of the quartz layers.

Whether the ore was deposited at the time of the coloration of the lower beds, or not, my observations do not determine. That the latter process was long subsequent to the formation of the quartzyte is clearly shown by the fact that the coloration proceeded inward from all joint-planes toward the centers of the blocks, as already explained. This could not have been the case if the rock had not already become indurated and jointed

before it was bathed in the iron-bearing solution (which seems to have come from the surface and not from below).*

It is of course possible that this ferruginous liquid was derived from the ore-bearing portion of the beds at a time long subsequent to the deposition of the ore. Opportunities for a thorough examination on this point are not yet to be had. The test pits are only sunk to the surface of the rock, or a few feet into it, as the ore, if found at all, is found near or at the surface of the rock.

In places the quartzyte is somewhat conglomeratic. The pebbles are small, not larger than coarse shot. The conglomeratic layers are near the base of the series.

With the exception of the iron ore, this rock very closely resembles the Sioux quartzyte of southeastern South Dakota.

The quartzyte was nowhere seen in contact with any other rock.

Near the dam at the foot of Prairie lake, just north of the quartzyte exposure, is a narrow belt on which are thickly strewn many small boulders of greenish-gray sandstone. No rock like it is exposed anywhere in this region, at least I was unable to find any. As represented by the boulders it is a quartz sandstone, somewhat micaceous, of only moderately firm texture and inclined to split into flags.

It gives no indication whatever of the presence of iron oxide. The belt on which the boulders lie is some four or five rods wide. Passing across this belt toward the quartzyte area, the sandstone boulders are quite abruptly replaced by boulders of quartzyte, which occupy a belt perhaps ten or fifteen rods wide, beyond which the quartzyte in place appears in oval topped masses here and there, often hidden by the drift but showing fairly well all the way to the river, a half mile southeast, where the iron-bearing beds are seen.

It was my impression, while on the ground, that beneath the belt of quartzyte-boulders the quartzyte lies, and that under the strip covered with boulders of gray sandstone, beds of that rock must be (making due allowance for the southward movement, due to ice action).

* With reference to the coloration of the quartzyte it is obvious that there are two ways in which this might occur. If the greenish quartzyte contains iron in any form other than the ferric oxide, then simple weathering would produce the change noted. Nor is there any fact observable in the field that militates against this as the way in which the change in color occurred. As a rule the red coat is as firm as the green core. Microscopic study would determine this point.

The other way of accounting for the color change is indicated in the body of this paper.

Just across the river (north) lies a body of granite. Boulders of this rock are strewn for a short distance to the south of the granite. Then comes a stretch of swampy ground in which no boulders can be seen, and after that, the succession before noted. The relations of these rocks are shown by the section (figure 3).

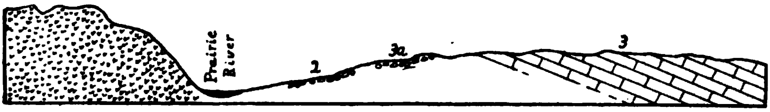


FIG. 3.—Showing stratigraphic relations at the falls of Prairie river. 1, granite; 2, sandstone boulders; 3a, quartzyte boulders; 3, quartzyte in place.

The depression which separates the granite from the near-lying quartzyte indicates the removal of some easily destroyed rock,—possibly the gray sandstone, possibly some other rock, no traces of which were seen,—lying between the tough granite on the one hand and the hard quartzyte on the other. No positive evidence, other than that just stated, supports this view of the stratigraphic relations here announced. On the other hand, nothing was found which opposes such a view.

II. PRAIRIE RIVER GRANITE.

This rock is exposed in the S. E. ¼ of the S. E. ¼ of sec. 32 and also in sec. 33, and very abundantly in sec. 34, T. 56, R. 25. It is seen to lie in a belt parallel to the quartzyte just described. It is a fine grained gray rock with some gneissic phases, and it contains some bodies of schist which were taken to indicate that the granite is eruptive. Its surface is quite uneven and is marked by roughly parallel ridges or corrugations, which mark lines of yielding to lateral pressure. These run in the direction of the outcrop, i. e., northeast and southwest. They are not high but are noticeable by reason of the incipient folding or bulging up of the rock.

Thrust planes are numerous and generally have either vertical or very steep dip.

Nothing like bedding was observed in this rock. Its relation to the quartzyte has already been noticed. The dip of the latter away from the granite shows that the region has been slightly uplifted, either by a general movement or by the intrusion of the granite. In T. 56-24, in the N. W. ¼ of sec. 9 and also in the eastern part of sec. 8, outcrops of a rock very similar to the granite rock at Prairie river, occur in the form of low

mounds, two in number, a half mile apart. The one in sec. 8 is low-lying and is exposed by the action of a small creek, for perhaps a quarter of a mile. The other outcrop, in sec. 9, is larger, rising perhaps fifteen feet above the little valley to the north. No other rock outcrops in this township. Test pits one mile south of the granite encounter the conglomeratic phase of the quartzyte, with very little ore. A half mile farther south the ore is found more abundant, and in the central and eastern parts of the township numerous pits have been sunk and in each the ore bearing rock was found.

The Diamond mine in the center of the township has been developed enough to show the presence of a considerable body of good ore. It was noticed in the sinking of these pits that the ore and rock were found at very different levels, e. g., one was sunk in a depression in the top of the highest hill in the township and another at the foot of the same hill. In the first case the ore was found at a level about that of the surface of the ground at the second pit. In the latter the ore was quite as far below the surface, which shows a difference of level in the rock surface of 150 feet in an eighth of a mile.

It is noteworthy that among the score of pits in this township not one seems to have touched the granite.*

Granite was reported in the next township north but it could not be examined.

III. DIORYTES OF THE BIG FORK OR BOWSTRING RIVER.

On the Big fork a few miles above the mouth of Rice river a ridge of dioryte about fifty yards wide crosses the river running north and south. The river runs at the south end of the ridge and then makes a bend and cuts squarely across it. The greater part of the ridge, which rises some twenty feet above the river, is on the left bank. Its length is less than a quarter of a mile.

The rock is a rather fine-grained dioryte with possibly some granitic phases. Quartz and colorless feldspar are the chief minerals. At the upper end of the exposure some reddish feldspar was seen.

A small dike of greenstone cuts the dioryte and runs N. W. by W. Up the river some two hundred yards from the south end of the dioryte, a low exposure of a dark basic rock, which looks a little like a gabbro, rises about three feet above the

*The rock here called granite has not been studied by me under the microscope hence I do not know that the rock is a granite. It may be a dioryte.

water at its very low stage. This may prove to be dioryte also but is decidedly basic. No contact of it with the dioryte could be found; nor could any extension of the latter be discovered in the woods on either bank. Five miles down the river another small body of dioryte, macroscopically indistinguishable from the exposure just noted, is found crossing the stream and disappearing in the banks. One hundred and fifty yards farther down is another mass of the same rock. This rock is black on the surface, but it may be that this is the result of its being covered by the stream at high water.

Perhaps five miles farther down the river is another body of the same rock. It shows in the bed and on the right bank of the stream. A number of large boulders four to six feet in diameter, apparently broken from this ledge, lie in the edge of the river and on the bank close to the solid rock. Their upper surfaces are striated and the striæ are parallel on the separate boulders and with those on the moutonnéed surfaces of the ledge.

IV. DIORYTE AT KOOCHICHING FALLS.

The Koochiching falls of the Rainy river are due to a ridge of quartz mica dioryte which is crossed by the stream about three miles below the outlet of Rainy lake. This rock forms the American shore for a mile below the falls, below which are two good sized islands of the same rock. It may appear farther down on the Canadian bank, but does not show itself on the U. S. side. This ridge of dioryte lies in the midst of a great body of mica schist* [Coutchiching of Lawson] through which it has been intruded. As evidence of this, many fragments of the schist of varying size are to be seen embedded in the dioryte.

Its character is better seen on the two islands than elsewhere. On fresh surfaces it appears as a light gray, rather coarse-grained rock made up of quartz, plagioclose, microcline and biotite. On weathered surfaces the color is faintly reddish, and large crystals of feldspar stand up prominently from the surface, giving a porphyritic appearance to the rock not seen in the fresh sections. At the upper end of the lower island a true porphyritic phase of the rock is seen. It changes notably in color and becomes finer in grain. At the upper end of the upper island a gneissic phase appears.

*Classed by Dr. A. C. Lawson as a mica syenite gneiss, Report on the Geology of the Rainy Lake Region, p. 126 F. (Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, vol. III, for 1887-88, Part F.)

A greenstone dike cuts the dioryte, passing through the upper island and then to the American shore, along which it was traced for a mile, or to the falls, where it crosses the river and disappears on the Canadian side. Like the dioryte, its trend is nearly east and west. It varies in width from three to ten feet. It is probably a diabase.

The dioryte is clearly younger than the schists, and the diabase dike is still more recent. Later still slight movements of these rocks have occurred, which have opened small fissures on the American shore and produced slight dislocations which are shown in the schists and also in the diabase dike.

V. THE GREENSTONES.

These appear in two distinct types, which, however, shade or merge into each other in such a way as to make it often doubtful whether one is dealing with one or the other of the types. When they appear as dikes, as they often do, they are of course plainly and purely eruptive. Also they may be and are found in such condition as to make it certain that we have to do with beds of consolidated tuffs. But again they are found in such condition that it is not possible to say to which class they shall be assigned. Along the Big fork these rocks constitute the chief exposures between Rice river and Big falls. These exposures are mainly low oval mounds or moutonnéed surfaces from which the river has removed the drift. No other rock is found associated with them. In T. 61-25 the greenstone forms considerable hills, fifty or sixty feet high, and extending for several miles. From the foot of Rice River rapids on the Big fork to Little falls no rock but greenstone is exposed, but the intervals between exposures are so great there is plenty of room for other rocks. At the Little falls the river pours over a large mass of greenstone which here shows nearly all gradations of that rock. Some of it seems from a microscopic examination to be eruptive. Other portions appear more like tuffs. No other rock occurs here. A fracture was noted running across the exposure.

Two miles down the river a small mound of greenstone is seen. This is the last noted except in the form of dikes. These will be noticed in describing the beds cut by them. At two exposures, one near the mouth of Deer river and the other a mile up that stream, pebbles or amygdules of quartz up to two inches in diameter were noticed in the greenstone. They have a little elongation which was thought to be due to squeezing.

VI. MICA SCHISTS.

These rocks with the intruded granites, etc., constitute an immense series, extending, on the Big fork, from a point about twelve miles by river below the Little falls to within fifteen miles of Rainy river. The exposure is by no means a continuous one for the drift is deep all the way down this stream, but erosion has uncovered the rock in places enough to indicate the continuity of the beds. On the Little fork mica schist was found within four miles of the Rainy river, while on Rainy lake the rocks are exposed in almost continuous section. Dr. Lawson* estimates their thickness on Rainy lake at four and a half miles.

The first exposure of these schists is about twelve miles below Little falls. The river runs in the schists for about an eighth of a mile. The rock stands up ten or twelve feet above the water. Two or three moutonnéed surfaces appear in the stream rising from one to three feet above very low water.

The rock seems to be composed almost wholly of biotite and quartz. The dip and strike were somewhat doubtfully made out by means partly of quartz lenses which were thought to indicate the bedding planes, and partly by means of a thin bed of green rock which was taken to be tuff.

As thus determined, the dip is some 30° or 40° west of north at an angle of perhaps 85°, and the strike east 30° or 40° north.

The schists are cut by a dike of greenstone, probably diabase, near the middle of the outcrop. It is twelve feet wide and strikes south 40° east.

Near the lower end of the exposure, in close proximity to the supposed tuff bed, an intrusion of granite is seen on the right bank. It is here twenty feet wide. On the opposite bank twenty rods away a narrow one foot vein of the same rock is seen. It is fine grained, light colored, slightly greenish, and extremely brittle.

At Big falls is a still larger exposure of mica schist veined with granite over which the river tumbles in a series of cascades falling about thirty feet in a quarter of a mile. Here the schists strike 8° or 10° south of east, but with local variations caused by the intrusion of the granite in the form of veins, sheets, bosses and dikes.

Two of these granite masses have flexed and contorted the schists in a very complex fashion. The dip is nearly vertical except where locally modified by the granite.

*Report on the Geology of the Rainy Lake Region, p. 102 F.

A dike of greenstone eighty feet wide cuts the schist parallel with the strike, near the head of the rapids. The schists are not notably changed at the contact with the dike. The granite sheets are very numerous. They run parallel with the strike of the schist and vary in thickness from less than one quarter of an inch to ten feet. The larger sheets do not follow the bedding of the schist very closely. They often show gneissic phases. This exposure extends for two miles along the river, but could not be found in the woods above the immediate valley.

A half mile below the mouth of the Sturgeon river—six miles from Big falls by river—mica schists veined with granite again appear. Apparently the same rock is seen at intervals in the river for twenty-five miles, always with a very steep dip to the north and with strike varying from east and west to southeast-northwest.

In the bed of Rainy river three miles below the falls a bed of fine-grained very hard mica schist is seen. It has a dip of 85° to the north and strikes east and west. Exposures of similar rock are found to within a mile and a half of the falls. Here it has been invaded by a large ridge of dioryte which has apparently carried it up so far that weathering and erosion have removed it, exposing the dioryte.

Four miles up the Little fork an exposure of mica schist of the same hard fine-grained type is seen crossing the river from northeast to southwest. This is also the direction of the strike. Dip vertical.

Above Ft. Francis at the Koochiching rapids, along the route through Rainy lake, Black bay, Kabetogama, Namekan and Sand Points lakes, and far up the Vermillion river, the schists were seen, sometimes free for long stretches from any intruded rock, and again seamed in every direction with granite.

There was usually a gradual increase in the abundance of the granite until it became the predominant rock, then in passing along the reverse conditions obtained until the simple schist was all that was to be seen.

No detailed work was done in this most interesting region, the time having been consumed in literally "beating the bush" in search of outcrops farther southwest in the region so thickly drift-covered that only rarely was the search rewarded with anything but negative results.

GLACIAL PHENOMENA.

I. THE TILL.

With some local exceptions, the till of the district is sandy, often gravelly. There is a notable scarcity of large boulders, in fact of boulders of any size except in cases to be hereafter specified.

The drift thins steadily to the northeast, so that by the time the southeast end of Rainy lake is reached only the depressions in the rocks are covered by drift.

T. 54–26 is one of the exceptions in that it is nearly all covered by a blue clayey till. This is doubtless due to the presence of the hills referred to on a previous page as possibly Cretaceous. There is evidence, in the shape of fragments of shale and pieces of lignite, that considerable areas of Cretaceous clays were to be found in this region at the time of the ice invasion. Blue clay lies under the till in many places in the southern part of the county. It was also noted along the Mississippi as underlying the sand and silt on the river bank from Grand Rapids to the swamp below Blackberry station.

No clayey till was noticed except in the immediate neighborhood of high non-morainic hills and ridges.

II. MORAINES.

A tolerably well-marked and continuous moraine enters this district in the southwest corner of T. 54–26 and runs northeast by north through three townships, leaving my territory in the northeast corner of T. 56–24.

The Mississippi river cuts this moraine two miles west of Blackberry station in the northwest corner of T. 54–24. At this point the morainic hills rise one hundred feet above the river. [A sand plain (overwash plain) lies along the east side of the moraine in T. 54–24 and the southern part of T. 55–24.]

Four miles north of the river the highest point of the moraine rises three hundred feet above Trout lake, in sec. 18, T. 55–24.

Somewhat disconnected morainic accumulations extend from the southern boundary of T. 54-26 north through at least six townships where they pass into a region not visited.

The frequent interruptions almost invariably transfer the moraine to the west, so that, while the segments trend about northeast by north, the moraine as a whole extends nearly due north.

This moraine has its strongest development in the southern half of T. 54-26, on the northwest flank of the high ridge of sup-

posed Cretaceous beds. It is also well developed in the northeastern part of T. 56-24.

Along both these moraines knobs and kettles are often well shown. The latter are in some cases one hundred feet deep.

One peculiar kettle is worth noting. It is in the top of the highest hill in T. 56-24, in sec. 21. The hill is about one hundred and fifty feet above the little stream near its base, and is quite separated from the adjacent hills. The kettle simulates a crater very closely. It occupies nearly the whole top of the hill, is about sixty feet deep and fifteen rods across the top of its narrow rim. The till is gravelly and quite bouldery. The boulders are well rounded and some of them well travelled. This is the only case that has come under my observation, of a large kettle in the top of an isolated hill.

III. BOULDER BEDS.

The scarcity of boulders in the till has already been noted. In one little area near the granite outcrop in T. 56-24 boulders were quite plentiful and some were of good size; but in all the rest of the district the till was found to contain but few boulders.

Whoever makes a canoe journey along either the Big fork or the Little fork in low water is not likely to complain of the infrequency of boulders in the bed of the stream. Scattered boulders here and there, more abundant than in the till, were to be expected. But that by no means tells the story. At all too frequent intervals the streams cross thick beds of boulders which extend in trains for unknown distances. In one case on the Big fork the same train was crossed three times in successive bends of the stream. They often occupy the bed of the stream for two miles at a stretch, but in such cases it is probable that the stream crosses the boulder train obliquely. On the Big fork these beds of boulders were first encountered about ten miles above the mouth of Rice river, and they were found at intervals all the way to within fifteen miles of Rainy river. The number of the boulders is astonishingly great. In some instances the river nearly disappears in the mass of boulders. More frequently it forms rapids, quite unfavorable to canoe navigation in low water. At the places where these boulder beds were found the country was almost invariably level. Exceptions to this are found in the vicinity of Deer river. There are no indications of the presence or proximity of a moraine. There are no signs of a rock outcrop. There are no boulders on the banks of the stream. They seem to be

confined to levels not far above that of the water. Whether these boulder trains mark the position of earlier moraines from which the other material has been removed, or whether they are combings from the bottom of the ice-sheet, I am unable to say. But from the extension of the belts, and from the fact that where outcrops occur no such boulder beds are found, and from the further fact that just above Deer river where a moraine crosses the stream boulder beds do occur, I incline to the former view.

IV. GLACIAL STRIÆ.

The following table gives the results of observations on the direction of striæ, as noted by me, referred to the magnetic meridian:

At Pokegama falls	S. 60° E.
At Prairie River rapids	S. 4° to 10° E.
On Big fork above Rice river, T. 61–26	E. 15° S.
On Big fork above Rice river, 40 rods down stream	E.
On Big fork below Rice river, T. 61–26	E. 11° S.
On Big fork below Rice river, T. 61–25	E. 15° to 45° S.
On Big fork above Deer river, T. 62–25	E. to E. 10° S.
On Big fork above Deer river, T. 62–25	E. 10° S.
On Big fork at Little falls	S. 12° to 18° E.
On Big fork 12 miles below Little falls	E. 10° to 22° S.
On Big fork at Big falls	E.
On Big fork below Sturgeon river	S. 34° E.
On Big fork 12 miles below Big falls	E. 18° to 22° S.
On Big fork 25 miles below Big falls	S. 34° W.
On Little fork 4 miles above Rainy river	S. 40° W.
On Rainy river 2¼ miles below Ft. Francis	S. 30° W.
On Rainy river 1½ miles below Ft. Francis	S. 30° W.
On Kabetogama lake near Black bay	S. 42° W.
On Namekan lake, west end	S. 30° W.
On Sand Points lake, 10 miles from Vermilion river	S. 12° W.
At Tower, south of Vermilion lake	S. 8° W.

Some interesting facts, relative to the direction of the ice-movement, are brought out by a study of this table. It is seen that there is a broad belt in which the movement, as indicated by the striæ, was to the east of south instead of west of south, as would be expected from previously observed striæ along the north coast of lake Superior and along the lakes on the International boundary. The abrupt change from southeast to southwest, as shown on the Big fork, is certainly suggestive, in view of the fact that the region is a very level one so that local topography can hardly be appealed to for an explanation. Hardly less looked for is the lessening of the westerly move-

ment noted in passing from Namekan lake to Vermilion lake, since the course is directly toward lake Superior. So far as I am aware, no suggestion of a cause for an easterly movement of the ice in this region has been made by any one. In fact, I think it has been generally supposed that the movement to the southwest along lake Superior and along the lakes of the International boundary, as far at least as to the Lake of the Woods, necessitated a parallel movement in the district lying between these two. That such was not always the case is shown by the evidence here recorded.

IX.

PRELIMINARY REPORT ON FIELD WORK DONE IN 1893.

BY J. E. SPURR.

CONTENTS.

ITINERARY.

The writer began his field work at the town of Virginia, in St. Louis county, where he arrived June 9, 1893. June 23d, he was joined by a competent assistant, Mr. R. P. Johnston of St. Paul, who remained with him throughout the rest of the season. Later in the summer, the change in the methods of work made it necessary to secure another assistant, and Mr. N. J. Cavanaugh was engaged at Mountain Iron, and continued in the employ of the survey from August 14 to November 7.

During the first part of the season it was convenient to make headquarters at towns and mining camps, along the Mesabi range, and from there to explore and map the surrounding country. Soon after my arrival the town of Virginia was destroyed by a forest fire, and during the rest of my stay in the vicinity, I, with many others, was indebted to the generous hospitality of Mr. R. B. Green. On June 27 we went to the mining town of Eveleth, in sec. 31, T. 58-17, where we made our headquarters; from Eveleth the next move was to McKinley; from McKinley to Biwabik; and from Biwabik to Mountain Iron. Having at length completed the survey of the Mesabi in ranges 16-19 west, a reconnoissance of the country to the north was undertaken. The services of Mr. Cavanaugh were secured, and on August 15 our party of three left Mountain Iron on foot, with a tent, camping outfit, and two weeks' provisions in our packsacks. Our route lay along the trail on the line between ranges 18 and 19, which we followed without difficulty, save in one case where a detour into T. 60-19 is made, and where nearly two days were spent in finding it. This brought us, in the northern part of T. 61-18, to the Sturgeon river road, which runs west from Tower to Sturgeon river. This we followed into Tower.

After some slight examination of the vicinity of Tower, two canoes were bought, and we left the town August 30 and made our way up the Pike river. The portages upon the upper part of this stream have been disused for some time, so that progress was somewhat difficult, and the old portage to the Embarras lakes was passed by unnoticed. We therefore kept on till we reached the county road, a few miles west of Merritt. From this point a portage was made to the Embarras lake at Merritt.

In order to gain some idea of the country lying south of the Mesabi range and north of the immediate vicinity of Carlton

county, our party set out again from Merritt September 6th, and canoed down through the Embarras lakes and Esquagama lake, through the Embarras river to the St. Louis river and down this latter stream as far as the crossing of the Duluth, Missabe and Northern railroad, at Albert. Some attempt was made to follow this river further down, but passage became progressively more difficult, on account of log jams, and the country was so unpromising for discoveries of geological importance that it seemed wise to turn back. At Albert, therefore, canoes and camp furniture were loaded into a train and carried to the crossing of the White Face river, at Kelsey. From here an expedition was made up the White Face river for some twenty-five miles, and back to the same point. After this trip the canoes were disposed of, and the rest of the season's work was done on foot, with the aid of railroads when these were convenient. For the reconnoissance of much of the southeastern part of St. Louis county, the Duluth, Missabe and Northern railroad between the stations Kelsey and Pine (on White Pine creek) was made a center and base of supplies. On September 28th we packed from Columbia Junction to Stony Brook Junction, on the Duluth and Winnipeg railroad at the St. Louis river.

From Stony Brook Junction we worked both east and west, using the railroad, as before, for our base of supplies. On the west, we worked past Floodwood; and on the east, down into Carlton county. On October 24th we crossed the St. Louis river at Nagonab on a log jam, and made our way north along White Pine creek to the Duluth, Missabe and Northern railroad. Crossing this, we kept on northward to the Cloquet river road, which runs westward from Duluth. Having from this route completed the reconnoissance of the southeastern corner of St. Louis county, the same road was followed westward, across the Cloquet and St. Louis rivers, to Floodwood; and thence north to Floodwood lake. From Floodwood lake north the trail could not be followed, but by pressing onward through the woods we reached the unfinished Duluth, Mississippi River and Northern railroad, and in a few days arrived at Hibbing, on the Mesabi range.

At Hibbing, Mr. Cavanaugh left us. From this point and from the various mining camps in the vicinity that part of the Mesabi range which lies in ranges 20 and 21 was carefully examined, so far as circumstances would allow, as far west as the Mesabi Chief mine in sec. 22, T. 57-22. When this task was

completed, the weather had become unfavorable for further work. We therefore left the field, and on November 18th Mr. Johnston and myself reached Minneapolis.

AREA MAPPED.

During the season sixty-two towns were roughly mapped, both geologically and to some extent topographically. When it is considered that these represent 2,232 square miles, and that all the information which we have in regard to them was obtained by one person in five months, and was secured in often unfavorable circumstances, it will be seen that there can be no possibility of having done careful and detailed work on most of the area, and the errors which will doubtless be detected may be fully accounted for.

GEOLOGICAL METHODS.

Somewhat careful and detailed work was done along the Mesabi range, in ranges 16 to 21. This is the most varied and interesting district in the territory examined, both geologically and topographically. Here the limits and relations of the different formations were carefully traced, most of the test-pits were visited, and a collection which was especially rich in the various phases of the iron-bearing rock was made. The opening up of the country by the exploration for iron, and the cutting of roads and trails, made this detailed study possible.

Outside of this district, however, the country was passed over at wide intervals, so that only a general knowledge of its features was obtained, which may be a guide to future work. There are some interesting special results, but, as a whole, it should be considered in the light of a reconnaissance.

TOPOGRAPHICAL METHODS.

Contour lines have been drawn for the whole area mapped, for each fifty feet above the level of the sea. In determining elevations the aneroid barometer was used, and sketching was often resorted to. Valuable checks were obtained at numerous places by hights determined by levelling, especially along the lines of railroad.

The most varied topography was along the Giant's range of hills, and here, where necessary, every section line was gone over and readings taken at short intervals. In the less varied country north of the Giant's range fewer determinations by barometric readings were possible, and sketching and to some

extent the use of the hand-level took their place. Much of the territory lying south of the range is exceedingly monotonous, so that the placing of the contour lines here was very simple.

SALIENT POINTS IN THE GEOLOGY.

Of the many varied and interesting observations which were made during the summer, it is the purpose of this report to give not more than a brief outline. The fuller discussion of the various problems involved will appear, or has already appeared, in various other publications of the survey, and elsewhere.

1. THE GIANT'S RANGE GRANITE.

It will be necessary first to speak of the granite of the Giant's range, although properly, in the order of its age, this should come after the Keewatin rocks. The granite, which is nominally of the hornblende-biotite variety, constitutes a continuous belt, several miles in width and upwards of a hundred miles in length, which runs about N. 70° E. across the area examined. The divide between the great drainage basins of the Red river on the north and the St. Lawrence system on the south follows for many miles this granite ridge.

Formerly, this granite had been generally assumed to represent sedimentary beds altered in situ, to be of Laurentian age, and to repose stratigraphically beneath the schists (of Keewatin age) with which it is associated. But the developments of this season's work show conclusively that this rock, whatever its earlier history and derivation, is in its present position intrusive, and is younger than the Keewatin rocks. The study of other granitic and gneissic areas in northeastern Minnesota has in other cases led to a similar conclusion,* and so the limits of the old Laurentian area have been considerably reduced.

The reasons for assigning to this rock an intrusive origin are those of the ordinary nature, and may be thus in part enumerated:

1. Contacts have been found, which show the granite sending stringers into the schists along the line of junction.

2. The granite contains numerous inclusions of the schists, and of all sizes. These fragments show various stages of

*Dr. U. S. Grant, Twentieth Ann. Rep. of this Survey, pp. 35-95; Twenty-First Ann. Rep., pp. 50-54. The probability of a large portion of the Giants' range being of the nature of eruptive rock was shown by Prof. N. H. Winchell in the Fifteenth Annual Report, pp. 349, 355; Seventeenth Report, pp. 21, 30, 31, 67.

metamorphism and recrystallization, which in general seem to vary with the size.

3. At the contact, the schists are more or less metamorphosed.

4. In two instances at least, the granite nearly surrounds areas of schist, which are, however, still connected with the main body. These peninsular areas show much greater metamorphism than the main body. (See Plate III).

5. In T. 58-17 are two lenticular masses of granite, separated from the main body, and surrounded by the schists. The longest axes of these bodies are parallel with the general trend of the main body; in mineral composition they are identical, and in texture they correspond to the phase in the main body which is commonest near the contact with the schists. They are undoubtedly the surface exposures of apophyses from the main mass.

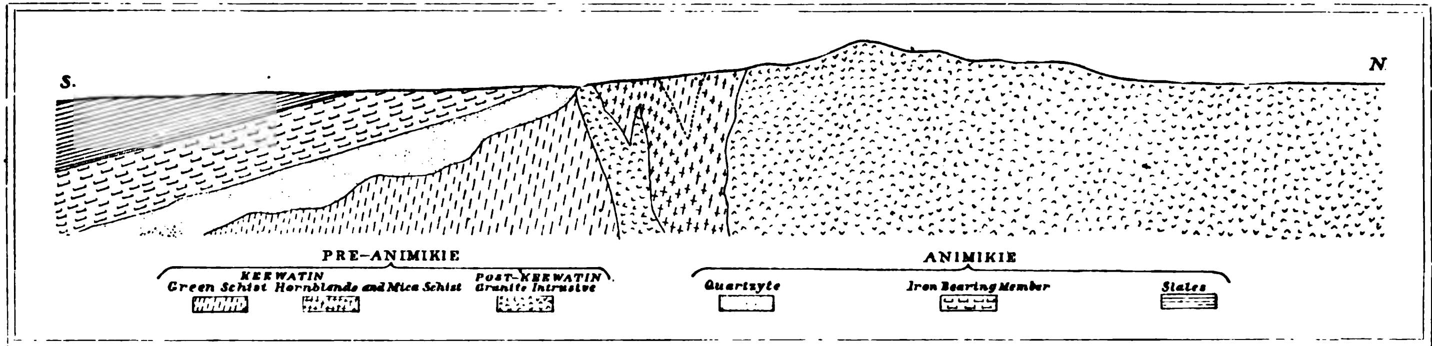
6. Near the contact, the granite is fine-grained; but as the distance increases, it becomes coarser and often porphyritic.

It is not possible to consider the question whether or not this granite consists of buried and fused acid sediments of the Laurentian, which by the movements of the inner crust were intruded among the later strata, and there recrystallized. The northern contact of the granite with the schists, though still distinct, is much more complicated than at the south, and this might suggest the idea that this is nearer the ancient granitic reservoir.

2. THE KEEWATIN SERIES.

Among the formations mapped was a hitherto unexplored area of Keewatin rocks, lying south of the granite belt above described. Frequent specimens were collected here, but no special microscopic study has been attempted. It is evident that the rocks vary in origin, some being undoubtedly igneous, while others have had a simple detrital origin. They are traversed by a regional cleavage which has a nearly uniform trend of about N. 70° E., and a hade which is nearly vertical. Most of the rocks are marked by the development of sericite and kindred minerals, resulting in the familiar "green schist" which has been considered the lithological peculiarity of the Keewatin.

Near the contact, however, as has been noted, and especially in those positions where they are partly surrounded by the granite, these schists have been altered into more perfectly crystalline hornblende and mica schists. The distribution and



SECTION ACROSS THE MESABI RANGE.

DRAWN NORTH AND SOUTH THROUGH THE CENTRAL PARTS OF TOWNSHIPS 58-18 AND 59-16, THUS PASSING THROUGH THE TOWN OF MOUNTAIN IRON.

Horizontal Scale $\frac{2}{3}$ mile=1 inch. Vertical Scale three or four times exaggerated.

This section shows the typical stratigraphy of the Western Mesabi range.

relation of these crystalline schists make it clear that they represent no distinct stratigraphical division, but are simply among the contact phenomena of the granite. (See Plate III.)

The chief interest in this lies in the fact that the hornblende and mica schists have in general been considered as peculiar to a lower horizon than the Keewatin—the Vermilion or Coutchiching,—and their existence has been held as sufficient evidence of the age of the rocks in any given case. In the district examined, however, it appears that this rule will not hold.

On the other hand, in those parts of the Keewatin further from the granite, especially in the southern part of T. 58-17, there were found rocks which were undoubtedly clastics, cleaved but not greatly metamorphosed, slates and quartzytes.

To sum up, there are in the Archean of the Mesabi range rocks which according to their lithological features might be held to represent three great horizons: The granites (sometimes gneissic), the Laurentian; the hornblende and mica schists, the Vermilion or Coutchiching; and finally the sericitic schists, the Keewatin. Actually, however, we are as yet unable to make any stratigraphical subdivision of the Archean in this place. In classifying the sericitic schists as Keewatin, we must assign to the same period all except the granite, and include the crystalline schists and the simple detritals.

*The Thomson Slates.**

The detrital series, which is well exposed in Carlton county, especially along the St. Louis river from Thomson to Cloquet, was traced for some distance further north than before known, into St. Louis county. The northernmost outcrop was in sec. 27, T. 51–19; and further north still the drift suggests that this continues to be the underlying rock.

These slates and graywackes have been sharply folded, and subsequently were subjected to strains which induced two sets of regional cleavage. Of these the most prominent, and apparently the first developed, varies from N. 60° E. to nearly east-and-west. Near Cloquet, where a later dike cuts the slates, a third cleavage is locally induced.

These rocks were correlated by Irving† with the Animikie of the Mesabi range, and subsequent writers have accepted this correlation. There seems to be a preponderance of evidence, however, in favor of considering them the equivalent of the

*Cf. "The stratigraphic position of the Thomson slates," by J. E. Spurr; Amer. Jour. Sci., III, vol. xlviii, pp. 159–166, Aug., 1894.

†Seventh Ann. Rep. U. S. Geol. Survey, p. 422.

Keewatin of the Mesabi range rather than the Animikie, and thus placing them below the great unconformity which is there displayed.

3. THE ANIMIKIE SERIES.

Upon the Mesabi range the rocks of the Animikie series rest unconformably upon the Keewatin schists. To the north they abut against the schists or the granite; while on the south they are covered by a great thickness of drift. The exposed belt thus follows the general strike of the strata, which in turn corresponds closely with the trend of the Giant's range of hills.

The observations upon the geology of the Animikie, and especially of the iron-bearing member, have been incorporated in Bulletin 10 of the survey. Excepting the belt above described, no other areas were encountered whose rocks were distinctly referable to this period.

4. THE CRETACEOUS BEDS.

The existence of certain small areas of conglomerates and shales which from their fossils proved to be Cretaceous has already been noted by Mr. H. V. Winchell.* These Cretaceous strata are found only in small, isolated areas, so far as is yet known; and these seem to be but the remains of a greater sheet which has been stripped away by erosion. They lie unconformably upon the Animikie strata; and in the places identified have apparently derived most of their material from the rocks of the iron-bearing member.

That they were laid down close to the shore is indicated not only by their conglomeratic and shaly characters, but also by the presence of numerous fragments of fossil wood, which are found imbedded among other materials. In one of the localities, moreover, a conglomerate of this sort is closely associated with a lignitic swamp deposit, showing that by a slight subsidence a coastal swamp had become transformed into a sea-beach. From the presence of these scattered fragments of purely littoral deposits, and the absence of any rocks indicative of deeper water conditions, it is possible that this region may actually have been the extreme limit of the Cretaceous ocean.

5. THE DRIFT.

Two moraines cross the area examined—the Mesabi moraine on the north, which in general follows the Giant's range of hills; and on the south, very near the junction of St. Louis and

*American Geologist, October, 1893, p. 220.

Carlton county, another, which has been identified by Mr. Upham with the Leaf Hills moraine, further northeast. In the nature of their composition, these two moraines are characteristic, and yet strikingly different. That of the Mesabi range contains boulders which, when of large size, are generally of granite, evidently derived from the Giant' range and the more extensive areas further north. The more southern moraine is characterized by the constant presence of large boulders of the coarse anorthosyte and other rocks which are found chiefly in the Keweenawan province, and so must have come in a southwesterly direction.

North of the Giant's range, as far as the Vermilion range, the drift consists mainly of till and little-washed gravels, but so scant in quantity that they determine the topography only to a minor extent.

Between the Mesabi moraine and that on the south lies an area which is nearly flat, but slopes gently toward the south. A large part of this is occupied by a swamp, of the common and well-defined variety which is called by the Indian name "muskeg."*

Where cuts have shown the nature of the soil which underlies the peat, it is usually of sand or stratified gravels. A large area lying chiefly between the St. Louis and the Floodwood river, is composed of a uniform siliceous clay, or extremely fine sand. This is not encumbered with muskeg.

Unmodified drift, however, encroaches upon the area in many cases. Noteworthy and interesting are the occurrences in the southeastern part, especially noted between Grand lake and the Cloquet river. Here in numerous cases cuts show a veneer of till, with many boulders (chiefly of anorthosyte and other rocks characteristic of the Keweenawan province), which covers an apparently deep deposit of fine, perfectly stratified sand. This must indicate a late advance of the ice after the deposition of most of the drift of this muskeg area; and the similarity of the bouldors in this till to those of the southern moraine suggests that they both may be referred to the same episode.

*This name is distinctive, and should be retained. The muskeg supports a thick growth of mosses and water-loving plants, and is always sprinkled with stunted spruce and tamarack trees. In distinction from the "cedar swamp" the muskeg or "tamarack swamp" is in the geological sense a true swamp, i.e., its soil consists of peaty material which represents the accumulation of vegetation in shallow bodies of standing water.

The Duchess slough.

The St. Louis river skirts the northern border of the southern of the two moraines described, and is thus deflected easterly from its previous course. In T. 50–17 it cuts across the morainic tract and resumes its southerly course. At the bend, near the junction of the river with White Pine creek, there is an interesting abandoned postglacial valley. This is now comparatively dry, or at most swampy, and is strongly marked for a large part of its course by distinct escarpments. The point of its leaving the present river channel and that of rejoining are within two miles of one another. This old river-bed represents an *ox-bow cut-off*, and differs from the ordinary occurrence in that the area enclosed by the cutoff is hilly and morainic. It goes by the name of the *Duchess slough*, and is the proposed northern terminus for the projected canal to furnish water-power for Duluth.

X.

LIST OF ROCK SAMPLES COLLECTED IN 1893

BY J. E. SPURR.

Most of the specimens were collected from the iron-bearing rocks of the Mesabi range; and from the study of these specimens have been derived many of the results which have been incorporated in Bulletin No. X of this survey. For the nomenclature of these iron-bearing rocks, and an explanation of the terms used, this bulletin should be consulted, especially the final discussion on page 248. All the specimens from the Mesabi range were taken from the general region included between ranges 16 and 21.

Many of the samples of other rocks were collected with a view to their bearing upon the problem of the iron ores; while others had no connection with this subject. The collection is intended to represent as completely as possible the known formations between Carlton county on the south and the region of Vermilion lake on the north, in ranges 16 to 21.

In general, this catalogue is to be considered as compiled simply for convenience of reference; the rocks are indicated by field names, which may often prove upon close study to be incorrect, and are perhaps manifestly indefinite. No study sufficient to permit of an accurate description of some of the rocks has as yet been made, except in the case of the rocks of the Mesabi iron-bearing formation.

Rocks of this series are numbered in white, each number followed by the letter S, to distinguish them from the other series of the survey and museum.

10. Gray taconyte (magnetitic). N. W. ¼ N. W. ¼ sec. 3, 58–17.

11. Light gray porous taconyte, banded with magnetite. Same locality.

12. Pale pink friable decomposed taconyte, stained brown in places by iron oxide. N. W. ¼ N. E. ¼ sec. 9, 58–17. Near the town of Virginia.

13. Hard lean iron ore (hematite). From the Rouchleau (Norman) mine, near Virginia.

14. Hard green taconyte, banded with magnetite. S. E. ¼ N. E. ¼ sec. 30, 58–17.

15. Granular quartzyte. S. E. ¼ S. E. ¼ sec. 29, 58–17.

16. Pebbly quartzyte, decomposed and stained red by iron. Same locality.

17. Dark green spotted-granular taconyte. S. E. ¼ S. E. ¼ sec. 30, 58–17.

18. Jointed taconyte slate. S. E. ¼ S. W. ¼ sec. 20, 58–17. From the face of a steep cliff.

19. Gray siliceous taconyte, changed in part to brown pulverulent rock. S. W. ¼ N. W. ¼ sec. 31, 58–17.

20. Siliceous and magnetitic taconyte, a pseudo-conglomerate. S. W. ¼ sec. 34, 58–17.

21. Taconyte breccia. S. E. ¼ sec. 30, 58–17.

22. Taconyte, pseudo-conglomeratic. Same locality as 20.

23. Fine-grained quartzyte. N. W. ¼ N. E. ¼ sec. 33, 58–17.

24. Gray slate. N. E. ¼ N. W. ¼ sec. 33, 58–17.

25. Taconyte, heavily magnetitic. Pseudo-conglomeritic. S. W. ¼ S. W. ¼ sec. 34, 58–17.

26. Hard hematite, coated with limonite or göthite. N. W. ¼ S. W. ¼ sec. 34, 58–17.

27. Sideritic chert banded with siliceous and chloritic slates. N. E. ¼ S. E. ¼ sec. 33, 58–17.

28. Taconyte slate (magnetitic) with residual fragment of red siliceous spotted-granular taconyte. Same locality.

29. Taconyte slate (magnetitic). Same locality.

30. Taconyte slate (magnetitic), jointed. Same locality.

31. Gray jasperoid taconyte, changing to light yellow pulverulent rock. From the Rouchleau (Norman) mine, near Virginia.

32. Gray jasperoid taconyte, altered in part to hard brown jasperoid taconyte. Same locality.

33. Green chert, with a finely brecciated band. From S. E. ¼ S. W. ¼ sec. 8, 58-17.

34. Gray siliceous spotted granular taconyte. Probably from sec. 17, 58-17, near Virginia.

35. Reddish taconyte jasper, banded with magnetite, and showing pitted decomposition. From Chicago property, in S. E. ¼ sec. 4. 58-16.

36. Light gray siliceous taconyte, showing pitted decomposition. Same locality.

37. Gray taconyte, impregnated with calcite or magnesite, and containing a fine-grained green residual fragment. Same locality.

38. Light green siliceous taconyte. Same locality.

39. Light green spotted-granular taconyte (green-sandstone?). Same locality.

40. Banded taconyte jasper, with bands of hard hematite. From Iron Cliff, S. E. ¼ N. W. ¼ sec. 36, 59-17.

41. Dark red siliceous taconyte, with sand grains. Same locality.

42. Gray jasperoid taconyte, changing to hard hematite, and stalactitic limonite. S. E. ¼ S. E. ¼ sec. 5, 58-16.

43. Altered conglomeritic quartzyte. S. E. ¼ S. W. ¼ sec. 4, 58-16.

44. Contact facies of mica schist. S. W. ¼ N. W. ¼ sec. 35, 59-17.

45. Mica schist. 45 paces north of 44, and nearer contact. Same locality.

46 Actinolite (?) schist. Same locality as 45, within five feet of contact with granite.

47. Contact of granite (hornblende biotite) with Keewatin schist. Same locality.

48. Biotite schist, in contact with granite, as above. From the main contact of the two formations. Same locality.

49. Contact of small stringer of granite with the schist as above. Same locality.

50. Granite (hornblende biotite) from within a few feet of the contact. Same locality.

51. Granite (hornblende biotite), like 50. From N. E. ¼ N. E. ¼ sec. 7, 58-16.

52. Granite, gneissic. About S. W. ¼ S. W. ¼ sec. 21, 59-17.

53. Dark green spotted-granular taconyte (green-sandstone?), in contact with black, carbonaceous shale. From the Chicago property, in the S. E. ¼ of sec. 4, 58-16.

54. Green schist, part stained brown by contact with the

iron of the iron-bearing rocks. From the Hale mine, S. E. ¼ N. W. ¼ sec. 1, 58-16.

55. Mottled greenstone. N. W. ¼ S. W. ¼ sec. 34, 59-16.

56. Dark, spotted greenstone. S. E. ¼ S. E. ¼ sec. 36, 59-16.

57. Mica schist. N. W. ¼ S. W. ¼ sec. 27, 59-18.

58. Hornblende schist. About 200 paces north of 57.

59. Mottled actinolite (?) schist. Same locality.

60. Muscovite (?) schist. Occurs interbanded with 59.

61. Conglomerate, probably Cretaceous. S. E. ¼ N. E. ¼ sec. 6, 58-17.

62. Conglomerate (probably Cretaceous), thoroughly iron-stained. N. E. ¼ N. E. ¼ sec. 10, 58-18.

63. Chip from boulder of hard iron in conglomerate. Partly magnetic, much pyritized. Same locality.

64. Red siliceous jointed taconyte, somewhat decomposed. S. W. ¼ S. W. ¼ sec. 2, 58-18.

65. Same as 64. Same locality.

66. Decomposed taconyte (pseudo-conglomerate). Same locality.

67. Conglomerate, thoroughly ferrated and changed to lean ore. Probably Cretaceous. Same locality as 62 and 63.

68. Brecciated taconyte, cherty and jasperoid fragments in a spotted-granular matrix. N. W. ¼ S. W. ¼ sec. 2, 58-18.

69. Postglacial taconyte conglomerate. From the drift, a mile south of Mountain Iron, in 58–18.

70. Banded silica-kaolin. S. E. ¼ N. E. ¼ sec. 6, 58–17.

71. Compact taconyte gritrock. S. W. ¼ N. E. ¼ sec. 3, 58–18.

72. Taconyte breccia. N. W. ¼ S. W. ¼ sec. 2, 58–18.

73. Same as 72.

74. Taconyte breccia, showing pitted decomposition. Same locality.

76. Dark gray impure limestone. N. W. ¼ N. E. ¼ sec. 7, 58–17.

77. Same as 76.

78. Dark red taconyte. N. W. ¼ S. W. ¼ sec. 2, 58–18.

79. Taconyte breccia. Same locality as 72.

80. Same as 79.

81. Taconyte hematite slate, jointed. S. W. ¼ N. W. ¼ sec. 3, 58–18.

82. Drill core of taconyte. S. E. ¼ N. E. ¼ sec. 6, 58–17.

83. Same locality. Slightly different phase.

84. Fragment (taconyte?). S. W. ¼ S. W. ¼ sec. 35, 59–18.

85. Taconyte pseudo-conglomerate. A decomposition phase. Same locality as 66.

86. Conglomerate (probably Cretaceous). Same locality as 82.

87. Same as 86, with incrustation of siderite (?). Same locality.

88. Consolidated carbonaceous clay (probably Cretaceous). Same locality.

89. Taconyte (?) shale. S. E. ¼ sec. 9, 58–18.

90. Same, banded. Silica-kaolin? Same locality.

91. Taconyte (?) shale. Same locality.

92. Same. Same locality.

93. Taconyte jasper. From the Snively property, S. W. ¼ N. W. ¼ sec. 3, 58–18.

94. Massive hornblende rock. S. W. ¼ N. E. ¼ sec. 17, 59–17.

95. Sericitic (?) schist. N. W. ¼ N. W. ¼ sec. 32, 59–17.

96. Taconyte jasper, with disseminated crystals of magnetite. N. E. ¼ N. E. ¼ sec. 23, 59–18. Probably from drift.

97. Taconyte jasper, with coating of limonite. From the rock-bluff to the north of Mountain Iron mine, 58–18.

98. Jointed magnetite slate (taconyte?), N. W. ¼ N. W. ¼ sec. 8, 58-18.

99. Taconyte chert, changing to taconyte slate, magnetitic. Same locality.

100. Reddish taconyte, changing to taconyte slate. S. E. ¼ N. E. ¼ sec. 7, 58–18.

101. Taconyte(?) shale. S. E. ¼ N. W. ¼ sec. 18, 58–18.

103. Same as 101. Same locality.

104. Preglacial wood. From drift. Same locality as 101, etc., and imbedded in the soft shale in part.

105. Conglomerate (probably Cretaceous). From drift at same locality.

106. Same as 105. Same locality.

107. Gray siliceous taconyte. S. W. ¼ S. E. ¼ sec. 2, 58–19.

108. Porous taconyte. S. E. ¼ S. W. ¼ sec. 8, 58–19.

109. Siliceous taconyte. Same locality.

110. Porous and siliceous taconyte. Same locality.

111. Siliceous taconyte, changing to taconyte slate, and coated with dendrites of maganese (wad?).

112. Sideritic and cherty slate. N. W. ¼ N. E. ¼ sec. 17, 58–19.

113. Same. Same locality.

114. Same, more definitely banded. Same locality.

115. Same. Same locality.
116. Same. Same locality.
117. Same. Same locality.
118. Cherty slate. S. W. ¼ S. W. ¼ sec. 17, 58–19.
119. Yellow taconyte gritrock, changing to brown taconyte jasperoid. N. E. ¼ S. W. ¼ sec. 17, 58–19.
120. Gray chert, changing to porous pulverulent rock (gritrock). Same locality.
121. Same. Same locality.
122. Cherty slate. Same locality as 112, etc.
123. Gray siliceous taconyte, changing to taconyte slate. S. E. ¼ N. E. ¼ sec. 17, 58–19.
124. Siliceous and decomposed taconyte, with coating of limonite. N. E. ¼ S. W. ¼ sec. 17, 58–19.
125. Glauconitic taconyte. From near 124.
126. Honeycombed limonite. From near 124 and 125.
127. Banded taconyte slate. Same locality as 123.
128. Siliceous taconyte. S. E. ¼ S. E. ¼ sec. 18, 58–19.
129. Taconyte chert. Same locality.
130. Same. Same locality.
131. Siderite-actinolite slate. Same locality.
132. Same. Same locality.
133. Taconyte gritrock, with seams of iron. 200 paces north of 128, etc.
134. Same. Same locality.
135. Siliceous taconyte, much altered to hematite. N. E. ¼ N. E. ¼ sec. 19, 58–19.
136. Porous taconyte, banded with hematite. Same locality.
137. Gray siliceous taconyte, impregnated with calcite or magnesite. N. W. ¼ N. W. ¼ sec. 17, 58–19.
138. Red taconyte shale. N. E. ¼ N. E. ¼ sec. 34, 58–20.
139. Cretaceous conglomerate (chiefly taconitic, much ferrated) containing fossil wood. N. W. ¼ S. W. ¼ sec. 20, 58–19.
140. Cretaceous conglomerate, containing fossil casts. Same locality.
141. Same. Same locality.
142. Cretaceous conglomerate. Contains pebbles of taconyte. Same locality.
143. Porous taconyte. Same locality as 135.
144. Cretaceous conglomerate, with fossil casts. Same locality as 139.
145. Green Cretaceous shale, with fossils. Same locality.

146. Sandstone conglomerate. From large drift boulder. N. W. ¼ S. W. ¼ section 10, 58–19.

147. Same. Same locality.

148. Taconyte gritrock, stained with iron in bands. S. E. ¼ N. E. ¼ sec. 17, 58–19.

149. Yellow taconyte jasperoid. N. E. ¼ S. W. ¼ sec. 10, 58–19.

150. Porous taconyte, changing to taconyte jasperoid. Same locality.

151. Gray porous taconyte, stained with iron on the periphery. Same locality.

152. Red taconyte shale. From near 148, etc.

153. Same. Same locality.

154. (Taconyte?) slate. From near 149, etc.

155. (Taconyte?) cherty slate. Same locality.

156. Taconyte gritrock, with seams of hematite. N. W. ¼ S. W. ¼ sec. 10, 58–19.

157. Gray taconyte, changing to red taconyte and taconyte slate. N. E. ¼ S. E. ¼ sec. 33, 58–17.

158. Banded taconyte slate. Same locality.

159. Gray taconyte chert. Same locality.

160. Same. Same locality.

161. Red siliceous taconyte, changing to taconyte gritrock. Same locality.

162. Hard hematite, with limonite. N. W. ¼ S. W. ¼ sec. 34, 58–17.

163. Same. Same locality.

164. Taconyte jasper, with quartz vein. N. W. ¼ S. E. ¼ sec. 33, 58–17.

165. Same, showing prismatic jointing. Same locality.

166. Gray and red taconyte. Same locality.

167. Incrustation of chalcedonic silica, in stalactitic forms, upon gray taconyte. S. E. ¼ S. W. ¼ sec. 8, 58–17.

170. Pitted taconyte slate, N. W. ¼ N. E. ¼ sec. 2, 58–18.

171. Taconyte breccia. N. E. ¼ S. W. ¼ sec. 1, 58–18.

174. Conglomerate (probably Cretaceous) stained red with iron. From N. W. ¼ N. W. ¼ sec. 11, 58–18.

175. Granite from contact with crystalline schists. N. E. ¼ sec. 12, 60-19.

176. Schist from same contact.

177. Granite from a dike in the schists. N. E. ¼ N. E. ¼ sec. 36, 61-19.

178. Schist from contact with granite. Same locality.

179. Actinolite (?) schist. From within a foot of the contact of the schists with the main body of granite, in N. E. ¼ sec. 12, 60-19.

180. Biotite schist. N. E. ¼ N. E. ¼ sec. 1, 60-19.

181. "Red jasper," with quartz vein. From the Minnesota mine at Tower.

182. "Black jasper." Same locality.

183. Siliceous jasperoid rock. Same locality.

184. Drill cores from near Lee mine, at Tower. "Jasper."

185. Banded jasperoid taconyte. From the Mountain Iron mine, at Mountain Iron.

186. Schist. S. E. ¼ S. W. ¼ sec 32, 61-16.

187. Fragment of gray calcareous nodule in slates, at Cloquet, near the Duluth & Winnipeg bridge across the St. Louis river.

188. Coarse gabbro. Duluth Hights.

189. Diabase (?) from center of large dike. Duluth Hights.

190. Diabase (?) from near margin of same dike.

191. Red rock. Duluth Hights.

192. More coarsely crystalline phase of same. Same locality.

193. Same. Same locality.

194. Red rock from narrow dike in coarse anorthosyte. Same locality.

195. Same. Same locality.

196. Diabase (?). Same locality.

197. Same. Same locality.

198. Red rock. Same locality.

199. Gabbro pebble, showing peripheral decomposition. From cut in drift, at Stony Brook station, on the Duluth and Winnipeg railroad.

200. Slate (Keewatin?). N. W. ¼ S. W. ¼ sec. 27, 51-19.

201. Quartzose slate. Same locality.

202. Schistose slate. Same locality.

203. Chips of fossil tree, found under a peat-bog, in the glacial gravels. From cut on D. M. & N. railroad one-half mile east of Pine station. (T. 50-16)

204. Hard hematite. Mountain Iron mine.

205. Quartzyte (Pewabic). N. W. ¼ N. W. ¼ sec. 36, 58-21.

206. Dark green quartzyte. Same locality.

207. Actinolite schist. S. W. ¼ S. W. ¼ sec. 25, 58–21.

208. Taconyte. N. W. ¼ N. W. ¼ sec. 36, 58–21.

209. Glacial boulder of taconyte jasperoid. N. W. ¼ N. E. ¼ sec. 1, 57–21.

210. Gray taconyte chert, changing to brown banded taconyte gritrock. S. E. ¼ N. E. ¼ sec. 29, 58–20.

211. Gray siliceous porous taconyte, changing to hematite. Same locality.

212. Gray siliceous taconyte, stained in part brown with iron oxide. N. W. ¼ N. W. ¼ sec. 22, 58–20.

213. Dark red jasperoidal taconyte. Same locality.

214. Gray siliceous taconyte, changing to brown taconyte jasperoid. Same locality.

215. Same as 213. Same locality.

216. Same. Same locality.

217. Glauconitic taconyte, with magnetite. Same locality.

218. Taconyte jasperoid, changing to hematite. Same locality.

219. Same as 217. Same locality.

220. Same as 213. Same locality.

221. Taconyte slate. N. E. ¼ S. W. ¼ sec. 29, 58–20.

222. Red taconyte shale. Same locality.

223. Green taconyte shale. Same locality.

224. Taconyte jasper. Same locality.

225. Gray taconyte gritrock. Same locality.

226. Quartzyte. S. W. ¼ N. W. ¼ sec. 35, 58–21.

227. Actinolite (?) schist. N. W. ¼ N. W. ¼ sec. 35, 58–21.

228. Muscovite schist. Same locality.

229. Silica powder. S. E. ¼ N. W. ¼ sec. 23, 57–22. Near Mesabi Chief mine.

230 Same. Same locality.

XI.

PRELIMINARY REPORT OF LEVELLING PARTY.

BY CHAS. P. BERKEY.

The party that entered upon work for the Geological and Natural History Survey on the 26th of June at Grand Marais consisted of L. A. Ogaard, Alex. N. Winchell and myself under the direct supervision of Dr. Grant. It was proposed to level across this portion of the state to the International boundary, to pay as much attention as practicable to the topography of the country as the levelling advanced, and to determine accurately by level such knobs or ridges as seemed of unusual elevation. The bench marks of the level were used as primary stations in the use of the aneroid barometer, by the aid of which the contour lines were established. The territory that occupied most of our attention comprises the central and northern portions of Cook county. This was known to be the most elevated district in the state and therefore considerable care was taken in an endeavor to locate more accurately the prominent points and ridges.

On account of the method of travelling in this district and the extreme difficulty of running a level through such a country of hills, swamps and poor trails, the work had to be planned by trips of two or three weeks duration. The first one of these was planned to extend from Grand Marais by the old "Iron trail" through Devil's Track lake, Little Pine lake, over Brulé mountain to the Misquah hills and then west to Winchell lake and south again to Brulé lake, where supplies had to be obtained again.

On a part of this first trip, which occupied the first three weeks of our work, we were obliged to engage two Indians, Jo Caribou and Alex Morrison, to help in packing and cutting through the

woods. This first trip was by a great deal the most difficult and tedious of the whole summer's work. The trail followed was old and abandoned, and in many places could not be found at all, even by the Indians. The character of the underbrush was such, furthermore, that it became utterly impossible to use the level at all without constant cutting. Frequently after the most diligent work, nightfall would find us little more than a mile in advance of the former camp. But this first trip, in spite of the enforced slow travelling and difficult work, gave, in fact, the most satisfactory results of the whole summer's expedition. The Misquah hills proved to be the highest points reached in Minnesota. Several knobs were accurately determined by level and many more by the aneroid, some of which are given in the list accompanying this report

The highest point on which direct observations were taken is between Misquah and Winchell lakes in sec 36, 64-2 W. It was carefully determined by barometric readings and corrected by level bench marks close at hand, as well as by level observations from neighboring hills. Its elevation is 2,230 feet above sea level,—there is no greater recorded in the state. The Misquah hills form a broken ridge extending east and west a distance of many miles just north of Brulé river valley. A few separated knobs also stand outside of this main ridge. But the area in which peaks of an elevation exceeding 2,200 feet occur is very limited, Misquah lake being nearly a central point. For a distance of three or four miles both east and west of this lake, this hight is attained by several knobs. The more exact position is in the southern tier of sections of T. 64, R. 1 and 2 W.

An opportunity is offered for a general view of the central portion of Cook county here. such as can be secured at no other place. Standing upon the bare knob of red rock just east of Misquah lake, a very large portion of the surrounding country can be seen in every direction and especially to the north and south. The minor details are thus of course entirely overlooked, and only important ridges bounding prominent valleys are noticeable.

Toward the north, the general impression is that of a broad quite uniform valley extending east and west an indefinite distance and bounded on the north by the bluffs and ridges along the International boundary ten miles away. In the valley a dozen or more lakes can be seen, while hundreds more are hid behind wooded ridges or lie in narrow deep secluded valleys. Toward the south are three well marked features.

First is Brulé river valley lying immediately at the foot of the hills, extending east and west here also, and bounded abruptly on the south by Brulé mountain and connected ridges. This valley is exceptionally narrow and deep, being nearly 600 feet below the Misquah hills and over 500 feet below Brulé mountain, while the maximum distance between these two points is not over four miles.

Brulé mountain is very prominent from this point of view. It lacks only 60 feet of equalling the Misquah hills in hight, and is even more striking. On its northern slope the descent is 521 feet in less than a mile (three-fourths of a mile). In this regard, however, it is not so remarkable as the first ridge at Grand Marais which ascends 730 feet in a mile, or even some of the bluffs along the International boundary which have an almost perpendicular face from one to two hundred feet in hight. Three miles east of Brulé mountain are three remarkable knobs belonging properly to the Misquah hills, although they are south of the river valley. They are near together and have an elevation of 2050 feet by aneroid reading on the lowest of the three. A hundred feet can safely be added to this for the highest one.

Just beyond the crest of Brulé mountain to the south lies lake Abita, the mountain lake of Minnesota, 2048 feet above the sea, the most elevated lake in the state so far as recorded. But beyond this is the third great valley in our general view of this part of Cook county. It extends almost east and west as the others, but is broader and not so uniform. The southern limit is formed by the Saw Teeth bluffs along lake Superior, several of which appearing quite prominent seem to give a very substantial boundary to the valley. Lakes are not so abundant in this most southerly valley as were afterwards found in the districts farther north and west. Swamps of no very great extent were abundant and often small ones occur near the highest points. Large drift boulders are found in abundance even upon the bare knobs of the highest of the Misquah hills. Very little attention could be paid to details in any other lines of investigation.

After obtaining supplies from Gunflint City, the work of our second trip began with topographical work about Brulé lake. James Marshall took the place of the two Indians who had returned to Grand Marais. Similar work was then carried forward through the country adjacent to the canoe route to Gunflint lake. Georgia, Surveyor, Ida Belle, Kiskadinna, and

Ham lakes are the principal ones on the route and Cross river is the only stream of any size. The surface slopes gradually northward with no very high ridges after leaving Surveyor lake until Gunflint lake and vicinity is reached. Some more careful work was done in T. 65-4 W., especially in the southern half of the town and in section 28 in particular. As all these points will appear just as clearly on the maps when they are published I will not attempt any explanation here.

The third trip of our party included towns 64 and 65, 1, 2, and 3 W. and was made by canoe through Loon, Mayhew, Tucker and Banadad lakes and eastward through a continuous chain of small lakes to Poplar lake. From this place a trip was made toward the south through Caribou to north Brulè lake in order to check on our former determination of level. The return was then made from Poplar lake through Hungry Jack, Birch, Duncan's and Rose lakes, from which the International boundary route was followed to Gunflint again. The most noticeable features of this section of country are: first the comparatively low and uniform ridges of the gabbro belt crowded thickly together with usually only sharp narrow ravines between them running in every direction; second, the bold-faced bluffs north of the gabbro belt within three miles of the boundary lakes. All these ridges are comparatively high and have a gradual rather gently inclined southern slope and a very precipitous northern one. The lakes are very abundant and lie in deep narrow valleys. They are connected frequently by falls and rapids, as at Rose lake where the fall from Duncan's lake is 136 feet in a distance of less than a quarter of a mile. One of the most noticeable of these characteristic precipitous bluffs is called Rose Lake mountain. It rises from Rose lake 470 feet by aneroid determination. The highest points are, first a hill on the section line between sections 26 and 35, 65-2 W., which is 2050 feet, and second, the quarter post on the north line of sec. 28, 65-4 W., which is 2038 feet. The former was determined by aneroid and the latter by level. Other features will be shown sufficiently well by the maps.

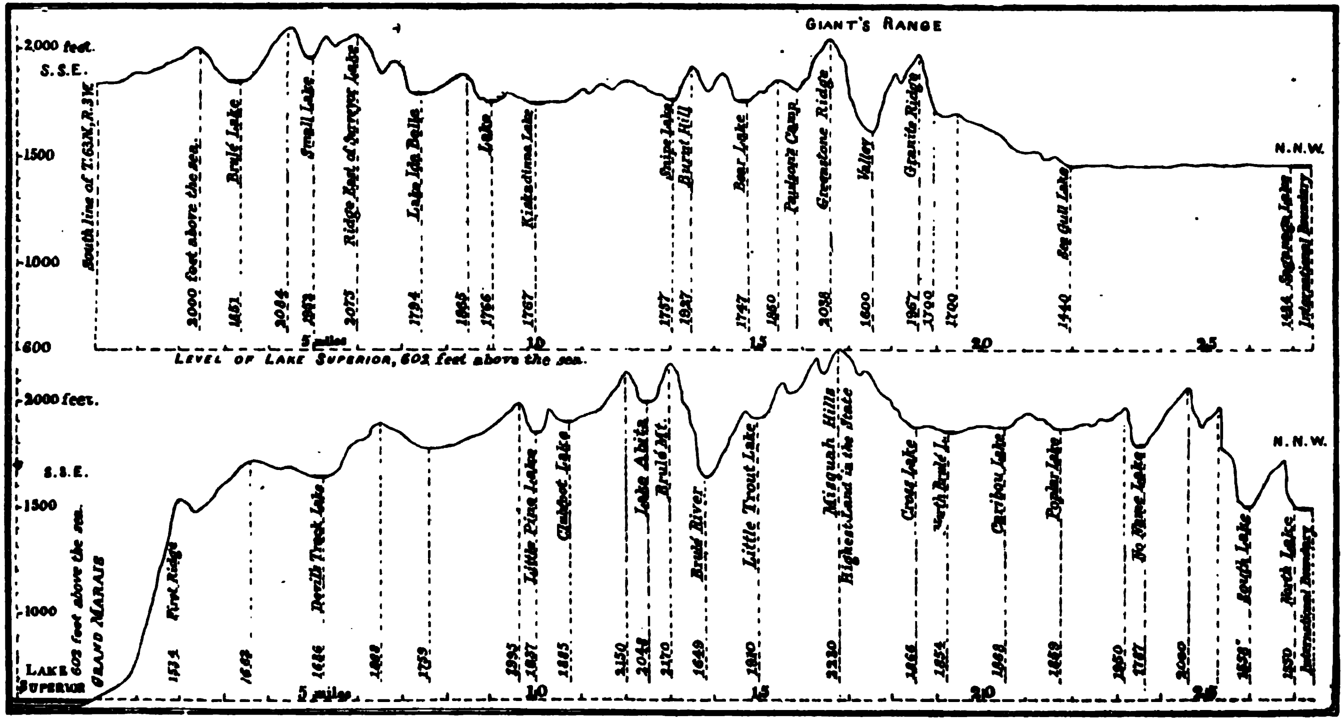
In the territory thus far covered since leaving Grand Marais a few other points come into prominence by combining the observations of the three trips. The hight of land extends in a southwest direction from between North and South lakes to the ridge between Ida Belle and Surveyor lakes. Lakes to the southeast of this line drain into lake Superior; and lakes northwest of it drain into Rainy lake. Brulé lake has two prominent

outlets, one toward the east giving rise to Brulé river, and the other to the west into Georgia lake, from which probably Temperance river rises, flowing toward the south. Ida Belle lake is the head of Cross river which flows north to Gunflint lake. For the greater part of its course it is a chain of narrow small lakes connected by rapids. North lake is the head of drainage westward along the boundary, and South lake is the head of the eastern boundary drainage, which reaches lake Superior through Arrow river in Canada and Pigeon river on the boundary. The Port Arthur, Duluth and Western railroad enters Minnesota at the narrows at the west end of Gunflint lake and the western terminus is now Paulson's camp four miles west. The county road extends from Grand Marais northward to Hungry Jack lake. During the past summer it was cut out from near Poplar lake westward to the railroad near the west end of Gunflint lake, and now forms a good trail from this point to lake Superior.

The fourth trip extended from Gunflint lake westward through Ts. 65–4and 5 W. and return through Ts. 64–5 and 4 W. There are no features of this needing especial attention. There are many very prominent hills, but none so high as those already given, the most elevated ones being usually between 1800 and 1900 feet.

After finishing this trip the entire original make-up of the party was broken by the return of Mr. Winchell and myself to the University. The further work was done by Mr. Ogaard, who then joined Dr. Grant, working on the geology of the district. And on their return to Ely the entire distance was levelled, thus completing a very extended list of bench marks as a basis for contour corrections in northeastern Minnesota.

Below I have added a list of accurately determined points from the field notes of the party, and have also, with the aid and advice of Mr. Warren Upham, drawn a plate showing two profiles across Cook county from Grand Marais and Brulé lake N. N. W. to the International boundary. These are each 27 miles in length and are about 10 miles apart. The one starting at Grand Marais includes only such points as fall within one mile of a direct line to the west end of North lake. The other, starting at Brulé lake, takes a direct line to the north quarter post of sec. 28, T. 65–4 W., and then runs northeast to the granite ridge, from which place it assumes the original direction to the boundary. (See plate IV.)



Two Profiles across Cook County, from Brule Lake and from Grand Marais N. N. W. to the International Boundary.

The following points are of sufficient prominence among those which have been accurately determined by level to warrant giving them a place here for future reference:

	Feet above the sea.
Devil's Track lake	1636
Little Pine lake	1837
Club Foot lake	1885
Pound lake	1920
Lake Abita	2048
Brulé mountain	2170
Brulé River lakes	1649
Little Trout lake	1910
Ridge S. of Little Trout lake	1994
Misquah lake	1911
Hill E. of Misquah lake	2223
Cross lake	1866
North Brulé lake	1854
Gaskanas lake	1878
Winchell lake	1910
Hill S. of Winchell lake in sec. 34, 64-2 W	2213
Sham lake	1915
Brulé lake	1851
Georgia lake	1841
Hill at W. end of Brulé lake, sec. 18, 63-3 W	2084
Surveyor lake	1849
Lake Ida Belle	1794
Narrow lake	1782
Kiskadinna lake	1767
Ham lake	1706
North ¼ post of sec. 28, 65-4 W.	2038
Gunflint lake	1547
Loon lake	1745
Mayhew lake	1853
Beaver lake	1880
Tucker lake	1847
Banadad lake	1944
1st lake E. of Banadad lake	1942
2d lake E. of Banadad lake	1927
3d lake E. of Banadad lake	1927
Poplar lake	1859
Straight lake	1879
Caribou lake	1868
Meeds lake	1879
Hungry Jack lake	1687
Birch lake	1684
Daniel's lake	1684
Duncan's lake	1664
Rose lake	1528
Rat lake	1531
South lake	1558
North lake	1550
Little Gunflint lake	1548
Akeley lake	1779
Paulson's lake	1708
Black Trout lake (Kakigo lake)	1663
Bashitanagueb lake	1657
Peter lake (Clothespin lake)	1608
Gabemichigama lake	1587
Agamok lake	1585
Little Saganaga lake	1600
Muscovado lake	1706
Green lake	1730
Gaiter lake	1782
Charley lake	1763
Bear lake	1748
Flying Cloud lake	1788
Greenwood Island lake	1641
East and West lake	1618

The following are on the canoe route from Gabemichigama lake westward to Ely:

	Feet above sea level.
Fox lake	1539
Ogishke Muncie lake	1488
Dike lake	1491
Zeta lake	1490
Epsilon lake	1460
Delta lake	1469
Gamma lake	1470
Beta lake	1475
Alpha lake	1495
Kekequabic lake	1497
Knife lake	1381
1st lake west of Knife lake	1371
2d " " " "	1367
3d " " " "	1361
Carp lake	1355
Sucker lake	1330
Basswood or Bassimenen lake	1300
Newton lake	1307
Fall lake	1313
Long lake	1337

The following are a few points of prominence determined by barometric readings and corrected by level bench marks:

	Feet above the sea.
South Devil's Track lake	1613
Knob S. of Little Pine lake	1995
Knob 3 miles E. of Brulé Mt., sec. 24, 63-1 W	2050
Hill N. E. of Little Trout lake	2023
Hill, sec. 36, 64-2 W., at Winchell lake	2230
Ridge S. of Brulé river, sec. 22, 63-2 W	2027
Granite ridge sec. 14, 65-4 W.	1967
Ridge south in sec. 23, 65-4 W.	1942
Sea Gull lake	1440
Ridge S. of Gunflint lake sec. 25, 65-4 W	1892
No-name lake	1787
Portage lake	1872
Hill S. of Hungry Jack lake, sec. 3, 64-1 W	1902
Moss lake	1729
Knob south of Duncan's lake	1907
Ridge between Duncan's and Rove lake	1947
Rose Lake mountain	1997
Hill, sec. 31, 65-5 W	1827
Hill, sec. 29, 65-5 W	1867
Little Round lake	1677
Little Copper lake	1777
Lake, sec. 15, 64-4 W	1867
Hill ½ mile west of this lake	1967
Snipe lake	1757
Burnt hill north of Snipe lake	1927
Big Round lake	1702

XII.

PRELIMINARY REPORT OF FIELD WORK DURING 1893 IN NORTHEASTERN MINNESOTA.

BY ARTHUR HUGO ELFTMAN.

CONTENTS.

GENERAL REPORT OF FIELD WORK.

I. REGION TRAVERSED.

The territory assigned for investigation was ranges 8 to 11 (inclusive) west of the Fourth principal meridian between the latitude of Ely and Snowbank lakes and the shores of lake Su-

perior. The writer, accompanied by Mr. H. E. White, as assistant and topographer, and Mr. B. F. Merrill, left Ely May 4th and spent the first week in making observations around White Iron lake. As soon as the ice had sufficiently broken up to permit canoe travelling, a trip was taken up the Kawishiwi river, north through Triangle, Moose, Snowbank and Disappointment lakes. Snowbank lake, excepting a narrow passage along the south shore, was covered with a field of ice. The work assigned on this lake was thus postponed until later in the season. Wilder lake completes the list of lakes examined during May. During June the region around the south Kawishiwi and Isabelle rivers was examined.

Some of the important lakes which were geologically reviewed and investigated, are Isabelle Trail, Bald Eagle, Gull, Gabbro and the eastern end of Birch lake. An overland trip through townships 60–11 and 61–11 was taken during the latter part of the month. The work was considerably hindered by the great forest fires upon the Mesabi range. The northwestern part of T. 60–11 was swept by the fire and the Stony river marks the eastern extent of the great conflagration. Numerous other fires were started by careless campers and large quantities of valuable timber were destroyed. During the hight of the fire the sun was obscured by the smoke for several days.

In July a trip was taken up the Stony river to Sand lake (T. 59–11) and to the center of T. 59–9. This river is so named on account of the large number of boulders in the stream, which greatly hinder and even make canoeing quite dangerous. From the Stony river the work was transferred to the south branch of the Isabelle river in T. 60–9. Heavy rains filled the streams and made travelling comparatively easy on the rivers, but almost impossible through the swamps. Owing to the unexplored condition of this region it was necessary to cut a number of portages. A canoe route was made from Smokehouse lake (sec. 28, T. 60–9) to Clear lake in section 14 of the same township. This makes a complete connection of the three principal canoe routes used in reaching the headwaters of the streams flowing north. From Clear lake we went down the south Isabelle river and returned to Ely. After getting supplies, several days were spent on Snowbank lake to make the observations which were postponed on account of the ice during our first visit to this lake.

We went up the south Isabelle river to Clear lake, from which a two weeks' overland trip was made through townships 61, 60, 59 and 58 of range 8. This was by far the hardest part of the summer's work. The region around Greenwood lake was next examined. The prominent elevation south of the lake was called Greenwood mountain. It is an oblong ridge about a mile long, extending in an east and west direction, a mile wide at the base, one half a mile across the top, one hundred and fifty feet above the lake and the surrounding country, which is nearly level and has an approximate altitude of 1850 feet above sea level and is covered with a heavy growth of green timber. From Greenwood lake it is the only ridge visible, and can be readily recognized by its peculiar form from the high hills at Disappointment lake, fifty miles north, and from the ridges around Beaver bay, seventy-five miles southeast. Greenwood mountain marks the most prominent western outcrop of the group of rocks called "red rock" on the map accompanying this report.

The examination of townships 58-11 and 57-10 and 11 was completed by the first of September. During the months of May, June, July and the fore part of August the supplies were obtained at Ely. In August a trip for supplies was taken down the St. Louis river to the Duluth & Iron Range R. R. and thence by rail to Mesabi.

On September 2d the headquarters were transferred to Two Harbors and Beaver Bay. At Two Harbors Mr. John Bean, an experienced surveyor and one well acquainted with the region to be examined, was employed in place of Mr. White, who left for Minneapolis August 23d. Three weeks were spent in the vicinity of Beaver Bay. Special attention was given to the relations of the anorthorsyte to the other rocks. Three excursions were made north from Beaver Bay to connect with the work carried on from the north during the fore part of the season. The remainder of the season was spent in working north of Two Harbors.

On October 20th the work assigned for the season was completed and the party disbanded.

II. ROUTES OF TRAVEL IN LAKE COUNTY.

The different routes of travel by which points in this region are made accessible will be given in groups under the places from which they start.

Ely Routes. The canoe routes along the International boundary and the Kawishiwi (Cashaway) river are well known and need no description. The Isabelle river route follows the Kawishiwi river to the portage in sec. 30, T. 63–10, passes through Clearwater lake to the south Kawishiwi river in sec. 32, T. 63–10, and then through Gabbro and Bald Eagle lakes and up the Isabelle river, which flows through the southern tier of sections of T. 62–8 and 9, to Isabelle lake in the southeastern part of T. 62–8. The main stream of the Isabella river crosses the northeastern part of T. 61–8, and comes from Bel lissima lake in the southeastern part of T. 61–7.

A short distance east of the portage in the center of sec. 34, T. 62–9, is the mouth of the south branch of the Isabelle river. This river, although of considerable size, spreads out near the mouth into low marshy ground and is almost wholly concealed. It flows in a zigzag manner in a northeasterly direction through T. 61–9, and in T. 60–9 it flows in a southwesterly direction. The river is canoeable to the lake in sec. 15, T. 60–9, from whence a portage is crossed to Clear lake in sec. 14, on another branch of the Isabelle river which flows northeast from there, and is not canoeable. From Clear lake trails connect with the Mesabi and Beaver Bay trail, and trails running through T. 60–8 and T. 59–8.

The Stony river route from Ely is through White Iron and Birch lakes, then up the Stony river which empties into the lake in section 30, T. 61-11, in a concealed bay nearly a mile long. From Birch lake to Slate lake the river is full of rapids and numerous portages must be crossed. The fall in the river through this distance is about 230 feet. On account of the difficulty experienced in going up the river to Slate lake, this part of the route is seldom used. The Harris lake route or the "60-10" winter road is taken instead. This road leaves Birch lake in the narrow bay in sec. 20, T. 61-11 and reaches Harris lake in sec. 27,—a distance of three miles (6,000 paces). Harris lake is 170 feet above Birch lake. From the east end of the lake the road runs southeast to Slate lake a distance of four miles, and follows the Stony river to Pike lake in sec. 36, T. 60-10. A portage from Pike lake goes to Smokehouse lake and the Isabelle river. At "Headquarter camp" in the center of sec. 21, T. 60-10 a short trail runs east through the center of Towns. 60-10 and 9 and crosses the southwest corner of T. 60-8.

For the portages on the Isabelle and Stony rivers, see the list of altitudes given below.

Mesabi route. This trail leaves Mesabi station, follows the Masabi range to the north town line of T. 59, and continues eastward along the same line to the northeast corner of T. 59-8 where it crosses Beaver Bay trail running northward. From here the trail continues southeast and eastward to Pork bay on lake Superior. Minor trails run north and south from the main one at different points. This is not a canoe route.

St. Louis river route. This route leaves the Duluth and Iron Range R. R. at the St. Louis river and follows the river nearly up to its source in T. 59-11 and then by a portage four miles long crosses to Sand and Stony lakes and the Stony river, or from Sand lake to Greenwood lake.

Cloquet route. A trail leaves the railroad at Cloquet river and runs to the north line of town 55 and east on the line to the lake in the northwest corner of T. 55-10. From here a good trail runs north to the two lakes in sections 29 and 31, T. 56-10 and east along the north line of sections 28, 27 and 26; then it takes a southeasterly direction to the northeast corner of sec. 35, and thence eastward across T. 56-9 to the Beaver Bay and Greenwood lake trail.

Highland route. This trail leaves the railroad one mile north of the station and is easily followed. In town 55-10 it has numerous branches and connects with the Cloquet trail.

Two Harbors trails. The county road runs along the lake shore from Duluth to Grand Marais passing through Two Harbors and Beaver Bay. A trail leaves Two Harbors and follows the line between ranges 10 and 11 north to the Highland trail. A number of minor trails leave here, but it is unnecessary to mention them as they are well known. From Two Harbors to Beaver Bay the usual route is by steamer.

Beaver Bay routes. Besides the county road there are several good town roads which run north into T. 56-8 and west to T. 55–9. From the end of the road in sec. 27, T. 56–8, a trail runs to Schaff's lake in sec. 12 and from the east end of the lake follows the range line north to the northeast corner of T. 59-8 where it connects with the Mesabi trail. The trail does not follow the range line very closely, but runs about one-half a mile east of it. The Greenwood lake trail leaves the town road in the center of sec. 9, T. 55–8, and runs nearly northwest to Greenwood lake twenty-four miles from Beaver Bay. An old and indistinct trail follows the line between ranges 9 and 10, between the Mesabi and Greenwood trails. A portage four

miles long connects Greenwood lake with Sand lake. In sec. 25, T. 56-9 the Cloquet trail connects with the main trail.

Among other trails which run north from lake Superior those following the Split Rock and Gooseberry rivers and the one on the line between ranges 9 and 10 are the only ones deserving to be mentioned. In T. 55–9 are a number of trails which connect with the more important ones given upon the map.

III. ECONOMIC RESOURCES OF LAKE COUNTY.

Upon this subject not much can be said. In the northwestern part of the county are numerous outcrops of iron ore, but beyond a few diamond drill sections, nothing has been done toward exploring and mining the ore bodies.* Towns 61 and 62 are nearly wholly within the gabbro area. Both of these towns are absolutely worthless, being covered with bare knobs of granite and gabbro, and with swamps in the valleys. Town 60 has a large amount of valuable timber, mostly white and Norway pine. The greater part of this when cut will be taken down the Stony river and thence to Fall lake, where a saw mill is in operation. Towns 59, 58 and 57 have scattering patches of good timber, but on account of the small quantity scattered over so large a region, and the inaccesibility of the same for the present, this has but little value. The greater part of these towns is covered with "muskeg" and almost impassable cedar ("tanglefoot") swamps. In T. 56 there is a large amount of good timber, the greater part of which is not yet large enough to be cut. T. 56–8 has considerable farming land. In Ts. 55–10 and 11 and 54–11 there is considerable timber which is widely scattered. The towns immediately back from the shore of lake Superior have good hay meadows and agricultural land. That farming can be successfully carried on in this region is shown by the flourishing farms around Beaver Bay. The region is not very heavily wooded. Maple trees are quite common.

IV. TOPOGRAPHY.

The topographical work consisted of drawing contour lines for every fifty feet in elevation above the sea level and the determination of the altitude of all prominent places. An aneroid barometer was used to determine the altitudes. Especial care was taken in obtaining the hights of the various lakes and

*H. V. Winchell, 17th Ann. Rep., pp. 120-127.

rivers along the more common routes of travel. Whenever possible the altitudes determined along these separate routes were checked with each other in order to eliminate any errors which might have arisen. The fall over rapids in the rivers when less than five feet was estimated.

The mapping of plates 78 and 79, embracing Ts. 61–10 and 11 62–10 and 11, and Ts. 62–8 and 9 and 63–8 and 9, respectively, was completed.

In Ts. 64-8 and 9 the region around Disappointment, Snowbank, Ensign and Moose lakes was mapped in connection with the geological work.

In the region south of plates 78 and 79 and north of the water divide between the streams flowing into lake Superior and those flowing northward, the principal determinations were along the Stony river to its source in T. 58–10; the Isabelle river and its southern branches; St. Louis river from the Duluth & Iron Range R. R. to its source in section 17, T. 59–11. The altitudes along the main lines were computed from the mouth of the rivers toward their source, and were checked at the following places: Seven Beaver lake on the St. Louis river to Sand lake which is tributary to the Stony river; Pike lake (sec. 36, T. 60–10), a widening of the Stony river, through Smokehouse lake (sec. 28, T. 60–9) to the South Isabelle river in sec. 27, T. 60–9, and then to Clear lake in sec. 14, T. 60–9 on the south east branch of the Isabelle river.

Region around Beaver Bay.—The work is this locality was carried on from lake Superior toward the interior and connections were made with the work on the north of the "divide." Ts. 85, 56, 57 of ranges 8 and 9 are included in this area.

North of Two Harbors.—The measurements taken in towns 52 to 56, inclusive, of ranges 10 and 11 are only approximate and in some cases are merely estimated.

The following altitudes or the more important places determined during the season's work have been corrected by Mr. Warren Upham and the writer. The fall in the rivers at the various rapids depends entirely upon the amount of water in the river. In a number of instances the short and low rapids disappear in high water, while in low water it is often necessary to drag a canoe for several miles through shallow water and continuous rapids.

Altitudes in Feet Above the Sea.

Determined by aneroid barometers; excepting several lakes designated by asterisks (*), whose hights are known by leveling:

	Feet.
Fall lake	*1313
Garden or Eve lake	*1384
Farm lake	1386
White Iron lake	1395
Birch lake	1410
Copeland's lake	1425
Fork of the Kawishiwi river, sec. 26, T. 63-10	1435
Crab lake and northeast elbow of Kawishiwi river in sec. 15, T. 63-9	1471
Ridges about ¼ mile north of the Kawishiwi river, in the northwest part of T. 63-9, about	1730
Large lake on the Kawishiwi river, in the southeast part of T. 63-9	1491
Lake of Kawishiwi river, sec. 33, T. 63-8	1520
Wilder lake	1540
Lake Alice	1544
Triangle lake	1490
North Twin lake	1475
Basswood (Basswood) lake	*1300
Sucker lake	1330
New Found lake	1331
Wind lake	1359
Moose lake	1339
Jasper lake	*1387
Snowbank lake	*1424
Ensign lake	*1342
Disappointment lake	1499
Disappointment hill, sec. 35, T. 64-8, about 1 mile east of this lake	1850
Gabbro lake	1464
Bald Eagle lake	1468
Lake on the Isabelle river, secs. 29 and 32, T. 62-8	1533
Lake Isabelle	1570
Bellissima lake	1650
Harris lake	1580
Slate lake	1640
Stony lake	1668
Sand lake	1674
Greenwood lake	1705
Greenwood mountain, sec. 30, T. 58-10, about 1¼ miles south of this lake	1850
Lakes in the west part of T. 59-11, at the head of the St. Louis river	1685
Seven Beaver lake	1675
Pine lake	1705
Pike lake	1700
Lake in sec. 22, T. 59-9	1745
Muck lake, at the head of Stony river	1755
Smokehouse lake	1740
Clear lake	1704
Adams lake	1800
Schaff's lake	1089
Bear lake	1160
Lake Superior, mean, 1870-1888, above mean tide sea level	*602

Portages on the Stony river.

From Birch lake (1410 feet above the sea) to Slate and Pike lakes and the lake in sec, 22, T. 50-9.

No.	Length.	Location.	Ascent in feet.	To altitude above the sea.
1.	⅛ mile	S. E. ¼ sec. 30. T. 61-11	10	1420
2.	¼ mile	N. E. ¼ of N. E. ¼, sec. 31, T. 61-11	20	1440
3.	1 rod	S. W. ¼ of N. E. ¼, sec. 31, T. 61-11	1	1441
4.	¼ mile	N. part of S. E. ¼, sec. 31, T. 61-11	6	1447
5.	⅛ mile	Crossing south line of sec. 31	24	1471
6.	⅛ mile	N. E. ¼ of S. E. ¼, sec. 6, T. 60-11	15	1486
7.	30 rods	N. W. ¼ of N. W. ¼, sec. 8, T. 60-11	20	1506
8.	⅛ mile	W. ½ of S. W. ¼, sec. 8, T. 60-11	69	1575
9.	¼ mile	S. W. ¼ of N. E. ¼, sec. 17, T. 60-11	15	1590
10.	¼ mile	North edge of S. W. ¼, sec. 16, T. 60-11	5	1595
11.	⅛ mile	S. W. ¼ of N. E. ¼, sec. 16, T. 60-11	7	1602
12.	8 rods	S. W. ¼ of S. W. ¼, sec. 10, T. 60-11	5	1607
13.	¼ mile	Central part of sec. 10, T. 60-11	5	1612

14.	Short rapids.	N.W. ¼ of S. E. ¼, sec. 10, T. 60–11 .... The usual portage instead of the last three is ¾ mile long, from the N. W. corner of sec. 15 to the N.W. ¼ of the S. E. ¼ of sec. 10.	2	1614
15.	¾ mile	E. part of sec. 11 and W. part of sec. 12 ...	10	1624
16.	½ mile	S. ½ of sec. 12, T. 60–11	10	1634
17.	1½ mile	Current and rapids to Slate lake..........	6	1640
18.	¾ mile	Across E. part of sec. 17, T. 60–10, to Chub lake....................................	15	1655
19.	¾ mile	S. E. through N. W. ¼, sec. 21, to Stony river at Headquarters camp, near the center of this section	10	1665
20.	Short rapids	N. W. ¼, sec. 34, T. 60–10, to Stony lake....	3	1668
21.	1 mile	Crossing N. W. ¼, sec. 35, to Pike lake	32	1700
22.	1 mile	S. ½ of sec. 31, T. 60–9.....................	28	1728
23.	Current and rapids	to lake in sec. 8, T. 59–9	11	1739
24.	Current and rapids	to lake in sec. 22, T. 50–9	6	1745

Portages on the south branch of Isabelle river.

In ascending the Isabelle river from Bald Eagle lake (1468 feet above the sea) a portage about a half a mile long is made in sec. 5, T. 61–9, with ascent of 50 feet, to 1518; and two short portages successively ascend 2 and 5 feet in the south part of sec. 34, T. 62–9, to the north of this south branch, near the middle of the east half of this sec. 34, at 1525 feet.

No.	Length.	Location.	Ascent in feet.	To altitude above the sea.
1.	10 rods......	S. W. ¼ of sec. 3, T. 61–9..................	1	1526
2.	½ mile	S. E. ¼ of N. W. ¼, sec. 9, T. 61–9	3	1529
3.	20 rods......	N. ½ of sec. 16, T. 61–9.....................	4	1533
4.	½ mile	S. ½ of sec. 16, T. 61–9	20	1553
5.	2 rods.	N. W. ¼ of N. E. ¼, sec. 29, T. 61–9.........	5	1558
6.	¼ mile	N. E. ¼ of N. W. ¼, sec. 29, T. 61–9	4	1562
7.	25 rods......	N. part of S. W. ¼, sec. 29, T. 61-9.........	8	1570
8.	½ mile	Near the center of the S. W. ¼, sec. 29.....	6	1576
9.	5 rods.......	S. W. corner of sec. 29, T. 61–9	7	1583
10.	¾ mile	W. ½ of sec. 32, T. 61–9, T. 61-9.............	45	1628
11.	½ mile	S. W. ¼ of S. W. ¼, sec. 5, T. 60–9...........	15	1643
12.	2 rods.......	N. W. corner of sec. 8, T. 60–9.............	3	1646
13.	¼ mile	E. part of N. W. ¼, sec. 8, to a small lake..	14	1660
14.	¼ mile	S. E. corner of sec. 8, T. 60–9..............	5	1665
15.	¼ mile	S. W. ¼, sec. 9, T. 60–9.....................	15	1680
16.	½ mile	S. E. ¼, sec. 9, and S. W. ¼, sec. 10, T. 60–9 .	20	1700
17.	10 rods.....	W. edge of S. E. ¼, sec 10, to lake in the N. E. ¼ of sec. 15, T. 60–9..................	4	1704
18.	¾ mile	From foregoing lake through N. ½ of sec. 14, T. 60–9, to Clear lake................	0	1704
19.	1 mile	From Clear lake southwest to the South branch of Isabelle river in the south edge of the N. E. ¼ of sec. 22. T. 60–9....	20	1724
20.	15 rods......	N. edge of S. E. ¼, sec. 22, T. 60–9..........	7	1731
21.	10 rods......	Central part of S. E. ¼, sec. 22, T. 60–9, to lake on the south line of this section....	7	1738
22.	½ mile	From foregoing lake southwest through the N. W. ¼ of sec. 27, T. 60, R. 9, to Smokehouse lake	2	1740

V. MAP OF THE WEST-CENTRAL PART OF LAKE COUNTY.

The map of the west-central part of Lake county which accompanies this report comprises townships 55 to 61 inclusive, of ranges 8 to 11 inclusive. Nearly one-half of this area is still unsurveyed. The surveyed townships excepting the southern tier of towns, T. 56-8 and T. 57–11, were surveyed within the last two years, The plats of the unsurveyed parts were compiled from data collected by the writer. The town and range lines have been run through this region and all points were located by pacing and running by compass from known points on these lines. In order to guard against errors, all necessary corrections were made in the field. The following towns are not surveyed: 61–8 to 11, 60–8, 59–9 and 10, 58–8 to 11,* and 57–8 to 10. Trails and portages are indicated by dotted lines and were fully described in a preceding section. The geological boundaries are indicated by the continuous lines drawn between the words *gabbro*, *red rock* and *diabase*. These terms are used as convenient designations for the three large groups of rocks included within this area, and will be explained in the geological part of this report. (See plate V.)

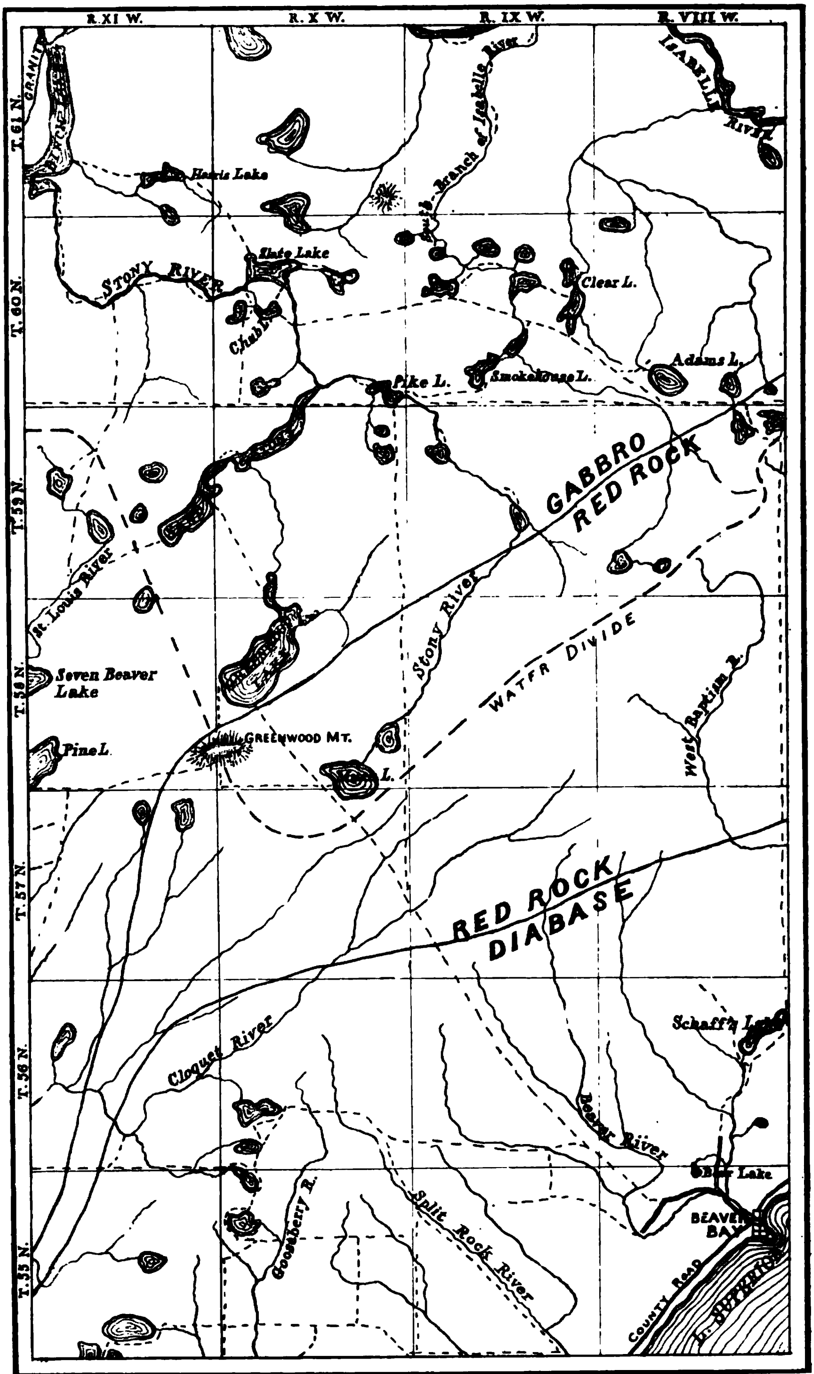
GEOLOGICAL NOTES ON NORTHEASTERN MINNESOTA.

I. INTRODUCTION.

The notes contained in the following pages are based upon observations made for the state geological survey. The laboratory work has been carried on in the laboratories of the department of geology in the University of Minnesota. Over three hundred thin sections have been made from specimens collected for the greater part by the writer. Lack of time, alone, prevents a more extended account of the observations made from being given at this time. The writer hopes in the near future to give in fuller detail the results of further examination of the Keweenawan eruptives of the north shore of lake Superior. In giving the township and range in these notes the township is always north, and the range is always west of the Fourth principal meridian, Minnesota, unless otherwise stated.

The writer desires to express his sincere thanks to Prof. C. W. Hall, of the University, and to Prof. N. H. Winchell and

*Since the above was written plats of towns 60–8 and 58–10 and 11 have been received from the Surveyor General.



MAP OF THE WEST CENTRAL PART OF LAKE COUNTY.

Dr. U. S. Grant, of the geological survey, for kind assistance given throughout the investigation.

II. SNOWBANK LAKE AREA.

Region north of the lake.

Observations on the rock outcrops on the shores of this lake are found in the 15th, 17th and 20th annual reports of the survey. The writer's attention was directed to the hitherto unexplored region extending from the north shore of the lake to Moose, Newfound and Ensign lakes. Between Moose and Snowbank lakes five cross sections were made. On the south shore of the former lake the rocks are sericitic and argillitic schists. The range of hills extending parallel with the lake shore is composed of vertical beds of schists, argillyte and conglomerate. South of these hills, at points from one-fourth to three-fourths of a mile distant from the lake shore and then extending southward through a swamp and valley, are extensive outcrops of quartzless porphyry. This rock extends nearly to Snowbank lake, on the west shore of which is also a ridge of schists and conglomerates.

The accompanying section, Plate VI, Fig. 2, (facing p. 160), from the N. E. ¼ of N. W. ¼ of sec. 35, T. 64–9, on Snowbank lake, N. W. to the ¼ of S. W. ¼ of sec. 22, on Moose lake, fairly represents the rocks north of Snowbank lake. The direction is nearly northwest and southeast, directly across the strike of the vertical formations. Beginning at Moose lake the numbers corresponding to those on the diagram denote the different kinds of rocks occuring along this section.

1. Sericitic schist. At the lake shore this schist is dark in color, fine grained and has a greasy appearance. One hundred and fifty paces from the shore at the base of a perpendicular cliff one hundred feet high is a light colored sericitic schist (165E) with small angular and round feldspars.

2. At the top of the cliff this rock grades into a schist (164E), in which the feldspar nodules have developed to well defined knots one-fourth of an inch in diameter. The schists stand nearly vertical, dipping at different places slightly to the north or south. The strike is about northeast and southwest, although in some places along Moose lake it varies from east and west to nearly north and south. Two hundred paces from the top of the cliff the rock has changed to a dark argillitic, sericitic schist (166E), in which the knotted structure has been dveloped to a greater extent. From the same out-

crop specimen 167E shows feldspars two inches long. The weathered surface here looks somewhat similar to that of the finely concretionary greenstone of Ely.

3. Two hundred and fifty paces farther and on the south side of a small swamp, is an extensive outcrop of argillyte (277E). This rock breaks up into small chips and tablets an inch thick.

4. Two hundred paces from the last outcrop, in a dense balsam thicket, is a knob of conglomerate fifty feet in diameter. In the conglomerate are numerous rounded and angular pebbles of jasper, varying in size from very fine grains to those three inches in diameter. Many of these pebbles show beautiful banding. Besides this jasper are gneiss, granite and slate pebbles not exceeding four inches in diameter. The matrix of the conglomerate is fine grained and green in appearance (276E). In another outcrop of this conglomerate fifty paces northeast of here granite boulders a foot in diameter are common. The conglomerate forms the highest part of the ridge south of Moose lake.

5. In the next one hundred paces there is descent of seventy-five feet into a swamp about a mile wide. Near the northern edge of the swamp is an outcrop of quartzless porphyry, which cuts the conglomerate and forms mica schist as a contact rock. In crossing the swamp there are occasional outcrops of porphyry.

6. In the N. W. ¼ of S. W. ¼ of sec. 26, T. 64-9, about two hundred paces west of Snowbank lake, the porphyry cuts a bed of conglomerate. This differs from number 4 in that no jasper pebbles were found.

7. In the conglomerate are beds of epidote schist, and the whole grades into argillyte. No distinct boundary between this bed and the preceding one can be marked out.

8. About four hundred paces southeast of number 6 and on the broad point in section 26 the argillyte grades into a hornblend mica schist which is considerably contorted and cut by a hornblende granite.

9. The granite continues to the shore of Snowbank lake in the N. W. ¼ sec. 35, T. 64-9.

Of this series of rocks the porphyry is the most important. Quartz porphyry dikes are of common occurrence in the Keewatin rocks of Minnesota, but in no place does it occur in such a large mass as it does west of Snowbank lake. Here it

extends in a northeast and southwest direction from the center of section 23, T. 64-9, through sections 27, 33 and 34, then westward to the west range line of T. 64-9, a length of five and one half miles; it varies in width from three fourths to one and one half miles. The rock is exceedingly hard, but owing to the basaltic structure, it readily breaks into angular blocks. The area in which this prophyry occurs is covered with these blocks. The readiness with which the prophyry breaks into angular blocks probably explains why it is found in a valley between ridges of mainly sedimentary rocks. Although these latter rocks are more easily abraded by the ice and at present decompose more rapidly, the porphyry being easily broken off in large blocks would be removed in much larger amounts leaving a depression between the clastics. When freshly broken the porphyry has a purple to grayish color. On a weathered surface the rock is white and occasionally is stained yellow or red by ferric oxide. Porphyritic crystals of feldspar are numerous; those of quartz are rare and in the larger number of specimens are entirely absent. Under the microscope felspar phenocrysts of all sizes, up to one fourth of an inch in length, are embedded in a microcrystalline groundmass of quartz and feldspar. The feldspars are orthoclase and oligoclase and show a more or less altered condition. In 60E the feldspar has been replaced by quartz. Quartz phenocrysts occur only in small quantities and sometimes are pseudomorphs after the feldspar. Chlorite and epidote occur in small flakes throughout the rock. Biotite and apatite are rarely present. Specimen 49*aE* represents the quartzose phase of the porphyry. In thin section, besides the usual constituents, there are numerous quartz phenocrysts. These, with but one or two exceptions, occur as round grains with corroded edges, and have a wavy extinction. The felspars are exceptionally well developed. Epidote is present in small plates and chlorite is scattered throughout the section.

Whenever the relations of the porphyry and the other rocks of this region could be determined it was found that the porphyry cuts the Keewatin rocks, sending dikes far across the strike of this formation. A great deal of the disturbance of the Keewatin rocks in this locality is due to the intrusion of the porphyry and not, as it is generally supposed, to the granite of Snowbank lake, which is the youngest formation in region. Dikes of granite (56E) cut the green schist (58E) and

the porphyry (55E) in the S. E. ¼ of the N. W. ¼ of sec. 26, T. 64–9. This is the only place known where the relations between the granite and the porphyry could be determined with certainty. The general strike of Keewatin sedimentaries is parallel to the periphery of the porphyry mass. On the west shore of Snowbank lake this strike is somewhat modified by the granite intrusion.

In going from the bay in Snowbank lake in the N. W. ¼ of S. E. ¼ sec. 24, T. 64–9, north 20° west to Newfound lake, the following outcrops of rocks were seen in the order given:

1. Mica schist and conglomerate in inseparable beds; the former becoming less schistose and micaceous as the distance from the granite area increases.
2. Argillyte.
3. Mica schist.
4. Coarse diabase.
5. Agglomeratic greenstone.
6. Conglomerate.
7. Argillyte.
8. Diabase similar to number 4.
9. Conglomerate and argillyte.
10. Sericite schist at three-fourths of a mile from Snowbank lake. This schist continues to Newfound lake.

The strike of the rocks mentioned above is nearly east and west, and toward the east this remains the same. One-half a mile west of the line of the cross section the strike of the rock is somewhat changed to a southwest and northeast direction. Farther west, near the north end of Moose lake, the strike, as previously mentioned, is nearly north and south.

In the region north of the central part of Snowbank lake no outcrops of the porphyry, which is so abundant west of here, were found. On the west shore of Boot lake, in the S. W. ¼ of N. W. ¼ sec. 21, T. 64–8, are several large dikes of this rock cutting the graywacke and schist in this vicinity.

In the S. W. ¼ of N. E. ¼ sec. 21, T. 64–8, on the east side of the long point, in the midst of a bed of conglomerate, is a boss of granite partially uncovered. Dikes run out from this mass in all directions, cutting the conglomerate and distorting the strata in a very complicated manner. In the conglomerate are boulders up to four feet in diameter of gneiss, slate, diabase and granite. This last can scarcely be distinguished from the granite which cuts the conglomerate of the region. In several

instances a granite dike traced several hundred feet was found to cut some of the large boulders in the conglomerate. The contact between the dike and the granite boulders could not be determined easily. Parts of the boulders adhered to each side of the dike.

The granites.

The granites of Snowbank lake present an interesting problem, as there is some evidence to show that two distinct granites exist here,—an augite and a hornblende granite. The field evidence at hand is not sufficient to warrant an assignment of any definite relations to these granites. The northern shore of the lake is made up of schists and argillytes with several small areas of granite occurring as dikes cutting the other rocks and on the extremities of some of the points projecting into the lake.

On the west side of the narrow bay in the W. ½ of sec. 20, T. 61–8, is a large outcrop of a light gray granite (271E). The rock is medium grained and the ferro-magnesian minerals constitute about one-half of the rock mass. Under the microscope this rock is shown to be an augite granite. Orthoclase, microcline and oligoclase occur in equal proportions. All of the feldspars have a well defined clear zone around a kaolinized center and are in some cases prophyritically developed. Quartz is not very abundant and occurs in small grains. The augite and hornblende are closely associated. The augite is of a light green color, has no pleochroism and extinguishes from 45° to 50°. It forms the cores of the hornblende which has a darker color, is pleochroic in brown and dark green and extinguishes at less than 22°. The cleavage of the hornblende is a continuation of that in the augite core. The line of division between the two minerals is distinct and the extinction angle of both minerals is readily measured along the same cleavage. One pyroxene plate is unaltered, and its extinction and striations bring it near to diallage. Hornblende occurs in several places in bent bundles of slender rods. Sphene occurs in double wedges and rounded grains. Magnetite and biotite are secondary and are not abundant.

Near the section line between sections 19 and 20 this rock (271E) is cut by a granite porphyry (270E). The specimen shows the porphyritic condition of the rock, which, as a whole, has a more even texture. In thin sections are found regular phenocrysts of orthoclase and oligoclase

embedded in a microcrystalline groundmass of quartz, feldspar and ferro-magnesian minerals. This rock also cuts and has greatly modified the schists and argillyte. As these hornblende and mica schists grade into the argillaceous slates and graywacke and have their most perfect developement at the contact with the granite, their highly crystalline condition is due to the action of the granite upon the other rocks.

On the east side of the bay mentioned above hornblende granite cuts the older rocks (273E). It has a medium texture and under the microscope shows the feldspars, quartz, hornblende, biotite and a yellow decomposition product, which stains the feldspars and is most likely limonite.

Since the discovery of augite in the granite from Snowbank lake the writer has, so far as time would permit, examined specimens collected by the survey. The following specimens are from this locality.

Specimen 521G*, from the S. E. ¼ of N. E. ¼ sec. 24, T. 64-9, is a fine dark hornblende granite. Under the microscope this shows the feldspars, hornblende, sphene and magnetite. The hornblende has altered to chlorite and shows no traces of augite.

522G, from the island in the N. E ¼ of S. W. ¼ sec. 19, T. 64-8. is an augite granite. The mineral constituents are the same as in 271E. Augite and hornblende are present in separate plates. There is no direct alteration of the former into the latter, but the hornblende possesses the fibrous cleavage of uralite and is a paramorph after the augite. Biotite is secondary from the hornblende. In this section we have a change of augite to hornblende, which in turn is altering to biotite and chlorite.

523G, from the N. W. ¼ of S. W. ¼ sec. 29, T. 64-8, is a medium grained hornblende granite of a light gray color. Examined in thin section, this rock shows the usual composition of the hornblende granite in this locality. The feldspars are considerably altered, quartz occurs only in small grains, and the hornblende is highly pleochroic in green and brown. Sphene is the oldest mineral. Magnetite is largely secondary. Limonite, an alteration product, stains the rock yellow. Combined with the kaolin of the feldspar this produces a yellow powder which is easily removed from the rock and leaves cavities. In the hand specimen this peculiar yellow stain is very noticeable.

*U. S. Grant, 20th Annual Report, pp. 66-67.

524G, from the east shore of the large island (Boot island) on the range line between T. 64–8 and 64–9, is a coarse augite granite. In general the rock is the same as 271E, differing only in the character of the augite, which in this section is fresh, shows no signs of alteration, is not pleochroic, extinguishes at 45° and has a deep green color.

1722 N. H. W., from the island in S. W. ¼ of S. W. ¼ sec. 30, T. 64-8, is a very fine grained granite with orthoclase, microcline and quartz phenocrysts in a microcrystalline base of quartz and feldspar. Hornblende occurs in small scattering plates and is greatly altered. Sphene, magnetite and limonite complete the mineral constituents.

From the above descriptions it is evident that this augite granite occurs at a number of places around Snowbank lake, and an examination of specimens from different outcrops in this locality will probably show a wider distribution of this rock.

Without going into the details of the field observations recorded in the 15th, 17th and 20th annual reports, it will be sufficient to say that all geologist have described two granites hitherto designated in the field as red and gray syenites. The former and of these is a hornblende granite and the latter an augite granite. The exact relations of these granites to each other and of the gray granite to the sedimentaries of this region are still doubtful. The gray granite has not been found in contact with the schists, argillytes and conglomerates of the region, and it is cut by the red granite which also cuts the schists. The most reasonable explanation which can at present be assigned to the occurence of these granites in the same area, is that they are parts of the same magma and that the hornblendic variety was erupted at a later dated and perhaps at a time of greater violence than that of the eruption of the augite granite, which formed the outer portion of the magma. As there is sufficient reason to place all of the eruptive pre-Animikie granites of Minnesota into one period, in comparing this area with the other granite areas the following facts must be considered: on Kekequabic lake the augite granite cuts the Keewatin sedimentaries;* in the White Iron lake area the dark hornblende granite, which corresponds to the augite granite, has the same relations to the Keewatin, as that in the preceding instance; in all localities where the light col-

*U. S. Grant, 21st Ann. Rep., p. 38.

ored granite is found, it is the later granite and has caused a greater disturbance than the augite granite; and wherever granite pebbles and boulders are found in the Keewatin conglomerate, they are almost wholly made up of light colored granite similar to that which cuts these older rocks. The last case is well illustrated by the granite on Boot lake, described on a preceding page.

Augite granite has been found only in two localities in northeastern Minnesota, viz., Snowbank and Kekequabic lake areas. In the granite specimens collected and described by Dr. Alex. Winchell as augite granite from White Iron and Saganaga lakes, a microscopical examination fails to show augite. The mineral taken as such is only hornblende, which occurs in dark masses varying in size from the lenticular patches a few inches in diameter to the irregular areas a fourth of a mile in length. A microscopical examination of a number of thin sections sections from these peculiar areas shows that the rock is composed of hornblende, occasionally some feldspar and rarely quartz. Biotite is due to the alteration of the hornblende. The sagenite structure of rutile is well shown in several slides.

In central Minnesota* the occurrence of the dark inclusions in the granite is the same as that of those just mentioned in the northeastern part of the state. The mineral composition, however, is somewhat different. In thin section these are found to consist of fresh augite or hornblende, with all degrees of alteration of the former to the latter, showing conclusively the secondary origin of the hornblende. Other evidence also shows that most of the hornblende granite of the same locality was originally an augite granite.

From the foregoing notes it is seen that the granite formation of Minnesota, which finds its greatest extent in the mountain masses of the Giant's range, although in the larger part of its area a hornblende granite, yet in other parts there are unmistakable proofs that it was originally an augite granite.

The present altered mineralogical composition of the granite is accounted for by the explanation suggested by Prof. N. H. Winchell to explain the great strength of Minnesota granites:† "We may perhaps account for the greater strength of Minnesota crystalline rocks by supposing them less changed superficially by the process of decay, the lateness of the glaciation

*For information concerning this locality the writer is indebted to Prof. C. W. Hall.

†N. H. Winchell. "The comparative strength of Minnesota and New England granites." 12th Ann. Report, pp. 14-18.

to which they have been subjected having left them comparatively fresh through the recent removal of a considerable thickness." Every one familiar with the occurrence of this granite formation will recognize the fact, that in the localities where augite has been found as one of the original constituents, the glacial action has been more pronounced and has removed a great thickness of the surface rock, up to that time undisturbed, leaving a much fresher rock than elsewhere, and in which one would naturally expect to find a facies of the formation nearer to its original condition.

In connection with the preceding it may be of interest to note that the hornblende and mica schists of Snowbank and White Iron lakes grade into argillaceous slates and conglomerates. The schistose character is most fully developed at the contact with the granite. All evidence tends to show that the schists are due to the intrusion of the granite and suggests that the narrow belts of schist generally found between the granite and the Keewatin rocks and which have hitherto been designated as a separate formation (Coutchiching or Vermilion) are only altered portions of the Keewatin which have been subjected to the heat and action of the intrusive granite.

III. ACTINOLITE MAGNETITE SCHISTS FROM THE EASTERN MESABI RANGE.*

The writer while studying the peculiar rock occurring along the central part of the northern periphery of the great gabbro belt, designated as the Pewabic quartzyte, found in the vicinity of Birch lake an extensive area of actinolite magnetite schists associated with the Animikie. The derivation of these schists from a rock containing a carbonate of iron and their lithological similarity to those found in the Penokee series tend to establish an important analogical link between the two series of which they are a part.

Since this investigation was carried on, actinolite schists from this locality have been described by Dr. W. S. Bayley.† These descriptions and the additional evidence obtained during the summer of 1893 confirm the views previously expressed by the writer.

*Extract of a thesis accepted for the degree of Master of Science in the University of Minnesota. Read before the Minnesota Academy of Natural Sciences, May 1, 1893.

†Amer. Jour. Sci., III. Vol. xlvi, pp. 176-180, Sept., 1893. The writer wishes to acknowledge the kindness of Dr. Bayley for the opportunity given to examine the slides used in his descriptions.

The accompanying map (Plate VI, Fig. 1,) of the west end of Birch lake gives a comprehensive view of the geological structure of this region. The contour lines were taken from the topographical notes of Mr. A. D. Meeds.

Numerous specimens have been collected by the state survey from this locality.* Nearly all these have been examined in thin section. In the following pages the descriptions of the occurrences of the field outcrops are taken from the annual reports of the survey, where more detailed accounts may be found. Beginning with the western extent of this area, where the Animikie approaches nearest to its normal condition found on the western Mesabi, the formation is traced through continuous outcrops to the north shore of Birch lake, where it disappears under the gabbro, and where the crystalline characters have the highest development. In studying the variety and the extremes of the lithological characters, and by noting the gradual change of one extreme into the other, we have undisputable evidence of the origin of the crystalline portions of the formation. The object of the following paper is to show the derivation of the actinolite schists and their relations to their geological associates in the vicinity of Birch lake. The fact that the so-called "Pewabic quartzyte," between Birch lake and Gunflint, is a part of the iron bearing portion of the Animikie will also be shown.

Specimens collected by Prof. N. H. Winchell.

The following specimens, collected by Prof. Winchell,† were examined in thin sections by the writer. Several diamond drill sections have been made under the management of Capt. Wicks. Of these the one (No. 5) on the N. W. ¼ S. W. ¼ sec. 27, T. 60–13, gives the most complete rock section as well as that of the greatest thickness. In ascending order the rock found here is as follows:

1636. Granite, 3 feet.

1635. Bottom of quartzyte, 1 foot.

1634. 10 feet. A hard siliceous greenish rock, which contains many fragmental grains of quartz. In thin section the quartz grains appear angular and show no signs of enlargement. They are derived from the granite, some contain numerous rutile needles and are full of inclusions. The matrix is composed of microcrystalline quartz and aphanitic green material

*H. V. Winchell. 17th Ann. Rept., pp. 81-96.
†21st Ann. Rept., pp. 82-86.

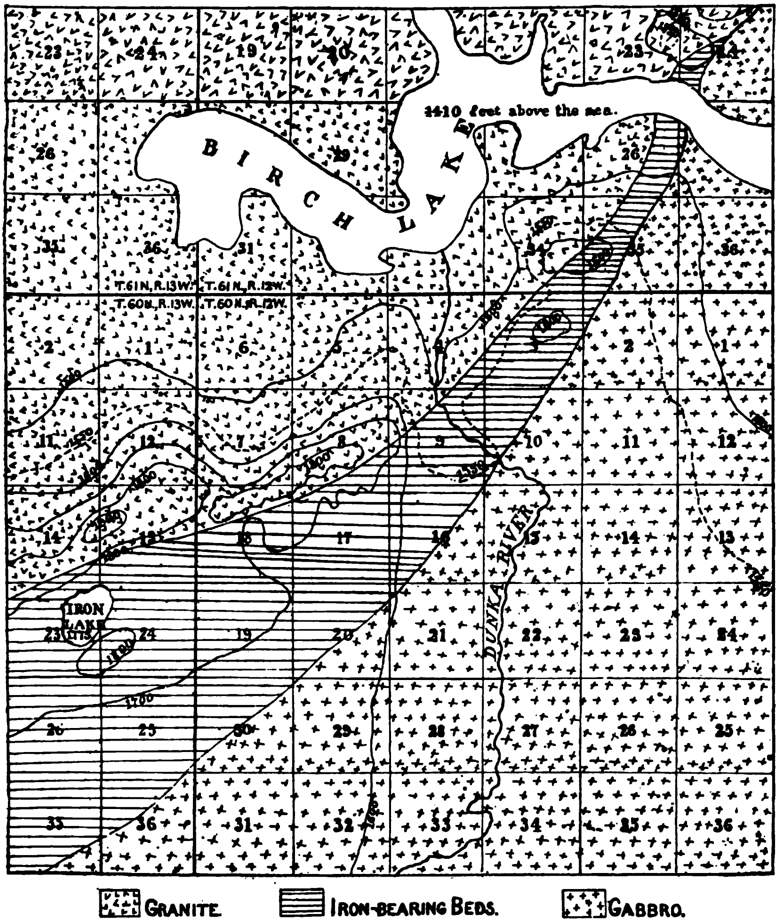


FIG. 1. GEOLOGICAL MAP OF THE WESTERN END OF BIRCH LAKE AND ADJOINING COUNTRY SOUTHWARD.

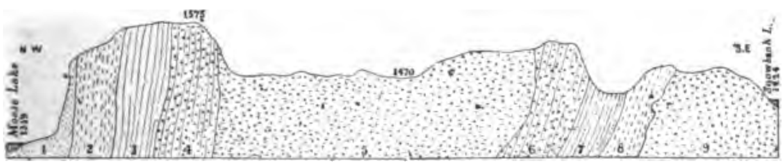


FIG. 2. CROSS-SECTION FROM MOOSE LAKE TO SNOWBANK LAKE. NORTHWEST TO SOUTHEAST. DISTANCE TWO MILES. ALTITUDES EXPRESSED IN FEET ABOVE THE SEA-LEVEL.

which has a tendency to form actinolite needles. These needles occur in bundles and in some cases penetrate the quartz grains. The transition upward to the next is gradual.

1633. 15 feet. Round fragmental quartz grains cemented in a matrix of quartz. In thin section this shows rounded fragmental grains of quartz embedded in a microcrystalline matrix of quartz and some green material. Some of the quartz grains show a slight enlargement, being bordered by a ragged rim of fine grained quartz with similar orientation.

1632. 17 feet. Fine grained pinkish-cream colored quartzyte. The hand specimen is composed of microcrystalline silica similar to the matrix of the preceding section.

1631. 24 feet. Siliceous, fine magnetite. On account of the high percentage of red hematite and magnetite this rock in thin section is nearly opaque. A few small grains of quartz were seen.

1630. 20 feet. Gray quartzyte, nearly all silica with round concretions. This is a magnetitic concretionary chert. Roughly oval and rhombic outlined areas of magnetite and hematite occur in a cherty background. The magnetite occurs in small cubes and the hematite is distinguishable only in reflected light by its red color. These two minerals occur in alternating bands in the same concretions. The iron oxides are often concentrated upon the exterior of the areas, and in some cases they have grown beyond the outer borders and extend into the cherty background.*

Another section from the same specimen shows a concretionary actinolitic chert. The concretionary structure is not so marked as in the preceding section. A considerable amount of a greenish mineral matter is present. Under a high power this shows the development of fine actinolite needles and plates.

1629. 70 feet. "Black slate" heavily charged with magnetite. Magnetite occurs in well developed crystals and composes nearly the whole section. Well developed plates of actinolite lie between the grains of magnetite.

1628. 157 feet. Black and gray, fine banded rock, with fine grained magnetite, the latter being distributed through the whole, and sometimes concentrated along planes of weakness in beds six to ten inches in thickness. The banding is wavy. A thin section of the drill core cuts the light and dark bands of the rock. The light colored bands are composed largely of

*Compare; R. D. Irving and C. R. Van Hise. 10th Ann. Rep. U. S. Geol. Survey, p. 490.

greenish aphanitic material showing numerous minute crystals of actinolite. Other portions of these bands have large plates of actinolite. The magnetite is concentrated along certain lines and extends into the actinolite bands. In places it appears in a roughly concretionary form. The actinolite in this section has been developed to a greater extent than that in the rock lower down in the series.

The above drill section represents a total thickness of three hundred and twenty-one feet. A number of other drills have been made in the same region. The succession of the different rocks is the same as that described above. The different strata vary in thickness as the extreme northern edge of the formation is approached. The only rock of uncertain thickness is number 1632, the fine grained pink quartzyte, which is absent in some places. The whole of the quartzyte is wanting a short distance east of this locality. A drill hole sunk in section 13, T. 60–13, passed through one hundred and ninety feet of hard "jaspery taconyte" banded with ore and resting upon the granite. The bands of ore were five or six inches thick, and the iron ore was hard, black and nearly always magnetic.

Specimens collected by H. V. Winchell.

In describing these specimens, they will be taken up in the order of their occurrence from the west toward Birch lake. Detailed notes of their occurrence may be found in the 17th annual report, and page references refer to this report and the numbers refer to the specimens.

373. (P. 86.) S. W. ¼ of S. W. ¼ sec. 32, T. 60–13. This is a black slate, and is composed of a clouded aphanitic mass of brownish material, which shows some clear pieces of actinolite. Magnetite is not very abundant.

369. (P. 85.) Iron lake, N. E. ¼ sec. 23, T. 60–13. A black magnetic rock lying nearly horizontal. The magnetite and siderite occur in well defined crystals. Part of the latter in thin plates is translucent. The green aphanitic mass of the rock has developed into plates of actinolite.

365. (P. 84.) N. W. ¼ sec. 24, T. 60–13. In a perpendicular wall eight feet high and several rods long of a heavy black rock. This is a concretionary actinolite slate, composed of aphanitic green material considerable developed to actinolite. Actinolite forms small oblong concretions, in which the fibers have a radial structure similar to that of the mineral in the zeolites. Needles and prisms of the amphibole penetrate and

cross these concretions. Magnitite is confined to the concretions.

364. (P. 83.) Is a conglomerate boulder.

363. (P. 83.) "A smoothed, black exposure of ferruginous quartzyte several acres in extent appears on the surface of the ground in the N. W. ¼ of N. E. ¼ sec. 19, 60-12." The rock and magnetite both weather shiny black. The specimen is largely composed of magnetite which occurs in concentrated parallel bands. Actinolite forms the light colored bands of the rock. It is present in small fresh prismatic plates 2 mm. in diameter.

362. (P. 82.) Near the last locality. Banded magnetite. This consists of several alternating light and dark bands. The latter are due to the concentration of magnetite which gradually decreases in quantity as the borders of the light bands are reached, and in the interior of these bands it occurs only in isolated grains. The light bands are composed of almost colorless grains of amphibole, the characters of which cannot be determined. This section represents an intermediate stage of developement between the slates composed of aphanitic and unindividualized green material and the actinolite magnetite schists represented by Dr. Bayley's specimen No. 8783.

361 and 360. (P. 82.) In the N. E. corner of sec. 19, T. 60–12, is a shaft about ten feet deep in a greenish magnetitic slate. Number 361 is a slate composed of unindividualized matter. Number 360 is a concretionary amphibole schist. The amphibole occurs in plates and irregular grains, having extinction angle of 14° to 25°. Actinolite and common hornblende are both present. Augite occurs in irregular plates, intergrown with the amphibole. The concretions of the ferro-magnesian minerals and magnetite lie against a background of medium grained quartz.

359. (P. 82.) In the S. W. ¼ of S. W. ¼ sec. 17, T. 60–12, is a magnetic quartzyte in strata dipping S. S. E. 10° to 12°. Under the microscope this rock shows the same characteristics as those of the preceding specimen. The green substance has not been fully developed to amphibole.

358. (P. 82.) "At one-fourth of a mile south of the S. E. corner of sec. 7, T. 60–12, are numerous angular fragments of olivinitic magnetite projecting through the moss." This rock is largely composed of microcrystalline quartz. The other constituents are magnetite, hematite and a green substance. This substance has partially changed to actinolite, forming

bundles of innumerable fine needles, some of which penetrate the quartz. Several rough rhombohedral pieces of a brownish mineral, probably siderite, are present. An indistinct concretionary structure is also noticeable.

356. (P. 93.) Iron ore, four hundred paces east of the west quarter post of sec. 10, T. 60–10.

396. (P. 93.) A short distance south of Birch lake in the N. E. ¼ of sec. 26, T. 61–12, is a knoll of fine grained crystalline rock. This is a fine grained gabbro. "The gabbro appears in small, detached knobs, lying on the Animikie iron ore beds. These beds are somewhat disturbed and broken and vary in dip from 12° to 30° to the southeast. Near these knolls of gabbro the iron ore rock is semi-crystalline, containing porphyritic crystals of hornblende sometimes two and one half inches long, 397. There are large outcrops of this Animikie rock here. Sometimes the stratification is not very evident, but generally it is distinct and well marked, 398."

397. In thin section this consists of large plates of actinolite, pleochroic in light and pale green and extinguishing nearly parallel. Cross sections of the crystals show the characteristic amphibole cleavage. Numerous small grains of quartz are enclosed by the actinolite, which in several cases forms around a number of the quartz grains a rim of inward penetrating needles. A few small pieces of plagioclase also occur. Magnetite occurs in small crystals in the actinolite.

398. The mineral composition of this is the same as the preceding, having in addition augite and olivine. It is of medium texture. Quartz occupies about one half of the section.

399. "Some of the Animikie is almost all quartz which forms a coarse granular sandstone on decomposing. E. ½ of N. W. ¼ sec. 35, T. 61–12." This is composed of interlocking quartz grains including magnetite and actinolite. The quartz interlocks by irregular sutures. The magnetite, which is the oldest mineral, is often in well marked octahedrons enclosed in the quartz, but more frequently it is in rounded grains, either surrounded by a quartz individual or situated between several of them. The actinolite holds the same relation to the quartz as does the magnetite. Both of these are somewhat altered to limonite and chlorite. In its present condition nothing remains to show a clastic origin. This character of the rock is common in the iron bearing member of the Animikie both on the Mesabi and on the Penokee ranges. It is largely on account of the abundance of this quartz in the so-called "Pewa-

bic quartzyte" between Birch and Akeley lakes that this part of the iron bearing member has been perhaps wrongfully referred to the basal quartzyte of the Animikie.

401. (P. 94). "In the S. E. ¼ N. E. ¼ sec. 35, T. 61-12, are several ridges of magnetic quartzyte having vertical faces 15 feet high on the west. A few feet west of one of these walls of rock there is a knoll of syenite. The quartzyte is in beds which are nearly horizontal and seem to have about the same texture and composition where it lies on top of the syenite as they have ten feet higher up, 401." This is strikingly similar to the preceding rock specimen. It is composed of large irregular interlocking quartz grains, hematite and magnetite, which shows the original concretionary form so common in the Animikie slate. A peculiarity in which it differs slightly from these other slates is, instead of a background of microcrystalline quartz, each of the concretions occurs in a separate grain of quartz. In some of the concretions the hematite and magnetite have a banded structure similar to that seen in jasper. A brown decomposition product, probably limonite, results from the decay of the iron oxides. The magnetite which does not occur as round concretions is arranged in bands through the rock.

402. (P. 95). "In the N. E. ¼ of S. W. ¼ sec. 35, T. 61-12, the magnetitic quartzyte seems to have been affected by some metamorphosing agent which has produced large crystals of hornblende in it." This is an actinolite magnetite schist. The actinolite occurs in plates and needles, which extinguish nearly parallel. The magnetite is irregularly scattered throughout the whole section. Quartz composes about one-third of the rock.

404. (P. 95). "Toward the S. W. ¼ of sec. 35, T. 61-12, the land rises until it is 200 feet above Birch lake. On this high land many large, smooth-topped exposures are produced by windfalls. The strata seem to have been disturbed and slightly elevated by some force from beneath. The usual dip—less than 30° to the southeast—is, however, still maintained. Some of the beds of this Animikie rock are but slightly iron bearing and are almost wholly composed of olivine, 404." A section of this rock is composed of two-thirds of quartz and the remainder of actinolite, olivine and magnetite. The quartz occurs in interlocking grains as described above. The other minerals occur as rounded grains within quartz grains or in masses between the grains. Innumerable fine tufts of actinolite needles pene-

trate the quartz grains in all directions. Numerous crystallites of the same mineral crowd the quartz, forming by their combination beautiful figures. A yellow decomposition product fills up the fractures in the quartz.

405. (P. 95). In the N. ½ of the S. E. ¼ sec. 24, T. 61–12, the general occurrence of the Animikie is the same as that south of Birch lake. Thin strata of rich magnetite are separated from each other by beds of poor ore or quartzyte, 405. Under the microscope this rock is found to be made up of quartz, actinolite and magnetite. The quartz occurs in rounded grains surrounded by the other minerals, and in irregular interlocking grains. The actinolite occurs in long slender plates and in bundles of needles. "There is a heavy covering of drift sand and boulders here. Granite in place and gabbro lying on it were seen a short distance farther east in the S. E. ¼ N. W. ¼ sec. 24, T. 61–12. The Animikie beds seen in the vicinity were in knolls that rise above the granite and gabbro and are estimated to be 150 feet above Birch lake. A thickness of about 25 feet of the iron-bearing strata was seen in the various shafts."

The outcrops just noted mark the eastermost extension of the Mesabi iron-bearing strata, which in the field have been found to be continuous and of the same formation, although varying greatly in lithological characters. Farther east are other isolated outcrops of this formation which will be mentioned below.

Other observations.

Other observations have been made in this vicinity by Prof. Winchell* and the writer.

In the S. E. ¼ of S. E. ¼ sec. 23, T. 61–12, a number of shafts have recently been made by the Spellman Mining Co., under the direction of Mr. W. L. Honnold. The largest shaft was sunk about 200 feet east of the granite. This passes through black slates, gabbro, iron ore and actinolite schist.

The following notes were given to the writer by Mr. Honnold: "The deepest shaft was sunk 37 feet deep,—7 feet surface, 20 feet magnetic ore and 10 feet hornblendic quartzyte (foot wall). Between the ore and foot wall is a seam three or four inches thick of chloritic material, very soft and probably resulting from the decomposition of the foot wall. The foot wall carries considerable ore in irregular distribution, and the ore passed through at first was apparently due to an unusual concentration of this. The 'black slates' were not encountered

*Twenty-first Ann. Rept., p. 156.

in the shaft, but are to be found near the surface about 300 paces east of this shaft. Whether these are a continuous formation or merely a local variation of the quartzyte is undetermined."

The so called black slates of this locality were found by the writer only in large blocks removed from their original position. They are the same as the black slates south of Birch lake, but as they are not found *in situ* north of the lake, they may be dismissed without further mention. All of the specimens obtains from this vicinity were examined in thin sections with the following results: The rock called the hanging wall in the largest shaft is a biotite gabbro of medium texture and considerably altered. This occurs as detached knobs resting upon the iron-bearing rock beneath it, in the same manner as the gabbro south of the lake. The magnetic ore is composed of a high percentage of magnetite, occuring in well defined cubes and rounded grains. The interstices between the grains are filled with plagioclase, augite, biotite and quartz, all of which are very fresh. The rock associated with the ore is composed of actinolite. This mineral occurs in large plates and bundles of numerous beautifully twined crystals. In places biotite and chlorite show the alteration of the actinolite. A few grains of quartz are scattered throughout the section. The "hornblendic quartzyte" is a fresh actinolite schist. The actinolite occurs in crystals several inches in length and encloses numerous quartz grains. This rock is the same in character as specimen 960 and described as an olivinitic quartzyte.* In thin section this rock is an actinolite schist similar to the schist south of Birch lake. The characters of the minerals in this section in every way correspond to those shown in Dr. Bayley's specimen No. 8783, from which it differs only in coarseness of texture. In this locality we have, thus, the actinolite schist and the magnetic ore occurring in alternating bands of great thickness. The original character of the rock has been totally obliterated and in its present condition the rock is wholly crystalline, representing one extreme of the variations in the lithological character of the Animikie schists.

Specimens collected by Mr. A. D. Meeds in 1893 are nearly all from the southern limit of the Animikie rocks.†

Number 2, is a fine grained gabbro, from the N. W. ¼ of N. W. ¼ sec. 2, T. 60-12.

*N. H. Winchell, 15th Ann. Rept., p. 335.

†See list of rocks collected by A. D. Meeds, pp. 87-89 of this report.

Number 2*a*, from an outcrop a short distance north of the N. W. corner of section 2, is the same as specimen 404 described above.

No. 5, is coarse gabbro, near the east quarter post of sec. 28, T. 61–12.

No. 6, from the N. E. ¼ of S. W. ¼ sec. 10, T. 60–12, is a fine grained gabbro.

No. 7, from near the east quarter post of sec. 17, T. 60–12, is the same as the actinolite schists described above.

No. 8, one-fourth of a mile south of the N. E. corner of sec. 35, T. 60–13, is a fine grained biotite schist. This is a part of the Animikie slate and is composed of quartz and biotite.

South of this locality the coarse gabbro occurs in numerous knobs and ridges. On account of the level topography in this vicinity the contact of the slate and gabbro was concealed by swamps.

Summary.

In the preceding notes attention is called to the varying lithological characters of the formation under consideration. This formation has been traced by continuous outcrops from the Mesabi iron bearing rock to Birch lake. At the western end the sedimentary character is undisputed. Going eastward the Animikie gradually thins out until it is lost altogether under the gabbro. The lithological characters also change, the nearer the gabbro is approached the more crystalline is the nature of the rock, until on both sides of Birch lake it is wholly crystalline. Near the contact with the gabbro, augite and olivine occur intimately associated with the actinolite and magnetite of the Animikie schists. The black slates have been changed to a quartz biotite schist in the proximity of the gabbro.

The lithological characters of the actinolite schists may be divided into two divisions: 1st. Those which are constant throughout the whole formation: banded structure, due to the concentration of the iron oxides along lines of weakness, leaving bands of lighter material, which finally makes up the ferromagnesian minerals; abundance of secondary quartz; concretionary structure of the iron oxides, and the presence of actinolite, although often in very small amounts. These characteristics agree very closely with those given by Irving and Van Hise* for the corresponding formations in the Penokee series.

*10th Ann. Rep. U. S. Geol. Survey, pp. 389-393.

The second division of the lithological characters is peculiar to the Mesabi formation, as they are largely due to the effect of the gabbro at the time of intrusion. 2d. Those characters which vary: mineralogical composition of the alternating bands. In the western part of the area, the light bands are composed of an unindividualized greenish substance, and the dark bands are composed of magnetite and hematite in about equal proportions, with some iron carbonate. Going eastward the rock passes through consecutive gradations until the light bands are made up of actinolite with local variations, where augite and olivine occur, and in the dark bands the hematite and siderite disappear, leaving only the magnetite. Plagioclase has been noted in several instances. Biotite results from the alteration of the actinolite.

The Pewabic quartzyte at the bottom of the Animikie decreases in thickness as Birch lake is approached from the west, and in the vicinity of Iron lake, section 14, T. 60–13, it disappears entirely. From this locality eastward the iron-bearing rock rests upon the granite, and consequently forms the bottom of the Animikie. The black slates also disappear before the Dunka river is reached. They were removed at the time of the gabbro intrusion.

The outcrops of the Animikie below and inclosed by the gabbro, between Birch lake and Akeley lake, have the same lithological characters and composition as the actinolite schists at Birch lake. These scattered outcrops have heretofore been called a part of the Pewabic quartzyte, but for reasons given above the writer considers them a part of the iron-bearing strata of the Animikie*.

IV. THE GABBRO.

Considerable time was spent in making a close study of the gabbro belt, through its entire width in Lake county. It is intended, on account of lack of time at present, to mention only a few of the localities where interesting observations were made.

In townships 62–10 and 11, and 61–10 and 11, an area about two townships in extent, of a dark, heavy and bedded olivine gabbro was found. Within this area are numerous knobs of feldspar rock as clear, fresh and coarse as the anorthosyte masses found near the lake Superior coast. In many instances

*Note.—W. S. Bayley, in the Nineteenth Ann. Rept., pp. 193-210, in describing rocks from the Akeley lake region, includes much of the so-called Pewabic quartzyte in the gabbro formation.

the feldspar knobs appear like water-worn boulders enclosed in the overlying olivine gabbro. On Greenwood lake (T. 58-10) are extensive outcrops of fresh hypersthene gabbro. This is cut in several places by dikes of the red rock which forms Greenwood mountain south of the lake. A point of importance in studying the gabbro is that the gabbro along the center of the formation has a belt in which are numerous knobs and areas a mile in extent composed of plagioclase rock, similar to that mentioned above. In going from the northern and southern limit of the gabbro toward this belt, it is very noticeable that the ferro-magnesian minerals decrease and the feldspar increases in proportion. The rock has more of a stratified appearance arising from the arrangement of the constituent minerals in bands. This separation of the minerals, when carried to extremes, produces the large aggregations of feldspar. The coarseness in texture is affected in the same manner. In the gabbro we have every evidence that it was a batholitic intrusion rather than a surface flow. The mineral and chemical composition of the various parts of the formation conform to all the known rules which govern the cooling of liquid magmas.

V. THE RED ROCK.

Under this group are included the felsytes, some of the diabases, and the augite syenite, which are closely associated and form a prominent group. The following are descriptions of all the outcrops examined by the writer, within the boundary of this group, as indicated on the map (Plate V, p. 150). In the N. E. ¼ of the S. W. ¼ sec. 8, T. 57-7, is the most northern outcrop of the dark diabases of the lake Superior coast. One half of a mile northwest of this, on the slope of a high ridge, are numerous angular fragments of augite syenite. At the top of the slope, rising four hundred feet in three fourths of a mile, is a perpendicular wall of fiery red augite syenite (225 E), similar to that found on the slope. The land continues at about the same hight north from here, and is covered with swamps. The rock is exposed in scattering outcrops and is the same as number 225E. Microscopical examination shows that this rock is the same as that described from Eagle mountain*. No augite was found in the section. Chlorite is present in small flakes. There are numerous patches of a yellow decomposition product which is easily removed, leaving a kind of porous

*R. D. Irving. Copper Bearing Rocks, Monograph V, U. S. G. S., p. 124, figs. 1 and 2, plate XIV.

structure. Quartz has thoroughly saturated the rock, and some of the cavities just mentioned are partially filled with quartz crystals, showing the progress of the saturation. The only original minerals definitely determined are orthoclase and oligoclase.

Seven miles north of the last outcrop, at the north quarter post of sec. 31, T. 59-7, is a large outcrop of felsyte porphyry, 172E. The weathered surface shows flowage structure on a large scale, 173E. Large black segregations show the peculiar bent and contorted condition noticed in the felsytes near lake Superior. In the N. W. ¼ of N. W. ¼ sec. 31, T. 59-7, are numerous angular fragments of laminated felsyte, 174E. This rock was not seen in place, but occurs in the outcrop one-half a mile east of here.

The next outcrop north of here is in the N. W. ¼ of sec. 36, T. 60-8. In the valley at this place is an exposure of black fine grained diabase nearly one half of a mile wide. The rock has a basaltic structure and in many places it is crossed by fine veins of quartz, 171E. Under the microscope the section shows long lath-shaped plagioclase, augite and magnetite. All of these are considerably altered. In portions of the section are porphyritic crystals of plagioclase. This rock is similar to the diabase cutting the felsytes north of lake Superior. It was not found in connection with the felsyte and augite syenite in this locality, but since in other localities it is always associated with these rocks it is safe to assume that it marks the northern edge of the red rock group in T. 60-8.

On Greenwood lake the gabbro is cut by dikes of augite syenite varying in width from one inch to two feet, 180E. This is the same as the rock which occurs in extensive outcrops south of the lake. Greenwood mountain is a mass of fiery red augite syenite, 185E and 186E. The rock is of medium texture, consisting mainly of feldspar and quartz. In ordinary light a section of this rock shows a red stained field completely riddled by secondary quartz. The quartz is wholly secondary and in many cases assumes a graphic form. The feldspar is mostly orthoclase with some oligoclase. These minerals have been corroded, broken up and replaced by infiltrating quartz. All of the quartz grains in any feldspar crystal are similarly oriented and in no case do those in adjacent feldspars possess the same orientation.

In the S. E. ¼ of S. E. ¼ sec. 1, T. 57-11, on the north side of the low ridge, are several outcrops of felsyte porphyry, 184E.

In microscopical characters it is similar to the following. Near the Beaver Bay trail in the S. E. ¼ sec. 33, T. 58–10, on the south side of the broad ridge, are extensive exposures of felsyte, 181E. "Large surfaces 'ten to twenty-five feet' square show fluidal structure on a large scale. Pale pinkish, light green and black felsytes are twisted together in various forms and assume a banded structure. The contrast between the colors is very strong. Under the microscope it is apparent that this rock is a felsyte with a quartz saturated base."*. The base is microcrystalline and of a red to purple color; the alternation of the lighter and darker portions gives a wavy banding to the rock. Red porphyritic feldspars are numerous.

A mile southwest of this outcrop and on the south side of the swamp which covers the region between the two, is an outcrop of felsyte porphyry, 182E, N. W. ¼ sec. 3, T. 57–10. Microscopical examination shows numerous orthoclase phenocryts embedded in a red to black aphanitic groundmass. The feldspar is somewhat altered to kaolin and shows shattering before the solidification of the base. The felsyte is cut by a fine grained diabase dike fifty feet wide, 183E. This is the same as the rock found in sec. 36, T. 60–8. South of these outcrops no others were observed, until in the S. W. ¼ N. W. ¼ sec. 4, T. 56–9, where the diabase of the lake Superior coast is found.

During the spring of 1892 Mr. C. L. Chase of Hastings, Minn., while surveying townships 56–9, 10 and 11, collected specimens from all of the rock outcrops upon the section lines in these townships. These specimens are registered in the general museum list and are briefly described as follows:

8026. Diabase from the S. E. ¼ S. E. ¼ sec. 4, T. 56-9. This is from the same outcrop from which 215E was taken.

8027. Anorthosyte. 1,500 paces north of S. E. corner sec. 5, T. 56–11. This is north of the red rock belt.

8028. Diabase. 25 chains west of S. E. corner sec. 2, T. 56–11. This belongs to the diabases south of the red rock.

8029. Felsyte porphyry, S. W. ¼ S. W. ¼ sec. 15, T. 56–11.

In the N. E. ¼ of N. E. ¼ sec. 4, T. 56–11, is a ledge of dark diabase, thirty feet high, facing northward and sloping toward the south, No. 8032. A short distance north of here on the north side of a small stream is a low east and west outcrop of gabbro, No. 8031. A dike of felsyte porphyry cuts the gabbro, No. 8033. Farther than this the relations of these

*Irving, op. cit. Description and illustration, p. 318.

rocks were not determined. The dark diabase is the same as that which was found cutting the felsyte in localities described above.

On the range line near the northwest corner of sec. 19, T. 55-11, Mr. A. D. Meeds found gabbro and felsyte porphyry in contact. From this exposure the relations of the rocks could not be determined. The region generally is covered with drift and swamp, which conceal all outcrops. One half a mile south of the last outcrop the felsyte again occurs. This probably represents the southern limit of the red rock belt in this locality. The specimens collected show red porphyritic feldspars embedded in a dark aphanitic groundmass. The gabbro is the coarse black phase of the great gabbro formation.

The bedded red rock surface flows of the lake Superior coast are traced by almost continuous outcrops into the great body of the red rock. The amygdaloidal and compact diabases cover the so-called fine grained gabbros or diabases south of the red rock group.

The varying composition of this group has been noted by other writers. Irving* says: "These three varieties of red rock [same as described above] thus described as occurring at Duluth, are evidently but different phases of the same rock, and without much doubt connected with each other in the mass, though this was not proved in the field." Although recognizing the fact that the different varieties of this group were found cutting all of the subdivisions, Irving places them in the different groups somewhat arbitrarily.

To the writer it seems that the Keweenawan on the north shore of lake Superior can be divided most satisfactorily into three large groups, with a possible smaller group, which in chronological order may be called the *gabbro*, *diabase*, *red rock* and the *later dikes* along the shore.

VI. THE DIABASES.

Under this group are included the fine grained dark gabbros so called, and the diabases forming Irving's different groups of the Keweenawan above the basal gabbro. Placing the amygdaloidal diabases and their related rocks in their proper position, i. e., into one large group, it is evident that the grouping of Irving must be readjusted. As a whole, this group is made up of a diabase porphyryte, which surrounds the anorthosytes.

*Copper Bearing Rocks, p. 272.

In the region back of the lake shore it is impossible to subdivide the rocks into the different groups of Irving. The lithological characters vary but little over large areas and would tend to show the unity of these groups rather than numerous subdivisions. The continuity of the rock outcrops in a measure serves to strengthen this view. This is the rock which transported the anorthosyte to its present position and represents the effusive portion of the magma, out of which the basal gabbro first cooled.

VII. THE ANORTHOSYTES OF THE MINNESOTA SHORE OF LAKE SUPERIOR.*

These rocks are discussed in detail by Dr. A. C. Lawson.† The first part of that paper takes up the petrographical characters. In the second part the distribution and mode of occurrence of the anorthosytes are discussed. These rocks were observed between Carlton peak and Encampment island, a distance of forty-six miles, and extend an unknown distance inland. The occurrence and character is described at the following points on the lake Superior coast: Encampment island, Split Rock point, Beaver Bay, shore below Beaver Bay, Baptism river, slope of Sawteeth mountains, Carlton peak.

In discussing the geological relations of the anorthosyte, it is considered as a pre-Keweenawan terrane for the following reasons: It is traversed by dikes, both acid and basic, of the Keweenawan eruptives; the Keweenawan lavas hold imbedded in them innumerable boulders and blocks of anorthosyte evidently detached from a pre-existing terrane; the anorthosyte forms the surface upon which the Keweenawan lavas now rest and upon which they were originally extravasated; the anorthosyte affords both by its petrographical characters and by the nature of its surface the most satisfactory evidence of profound erosion prior to the extravasation of the Keweenawan eruptives. A great interval must have elapsed during this erosion, and the recognition of a pre-Keweenawan terrane involves certain consequences of geological importance. One of these is the absence of the Animikie in the region of study; another is the correction of Irving's estimate of the thickness of the Keweenawan. Instead of 20,000 feet in thickness, this is placed at barely 2,000 feet. The anorthosytes are plutonic

*Read before the Minn. Acad. of Nat. Sciences, Dec. 26, 1893.
†Bulletin No. 8, pp. 1-25, 1893.

eruptives, invading the Archean and yet long anterior to the Animikie. *Carltonian* is suggested as a local name for the formation.

In view of these conflicting opinions, the writer was instructed to make a detailed examination of the field relations of the anorthosytes and the associated rocks. While engaged in this work all of the localities, except Carlton peak, mentioned in Bulletin No. 8, as well as all the outcrops existing farther inland, were examined. The following notes bear chiefly upon the areas of the anorthosyte existing farther inland, and not described before. These observations confirm the views of N. H. Winchell, Irving, and others, in that they considered the anorthosyte masses as *detached blocks* inclosed in later trap rocks.

The geological relations of the inland anorthosyte areas are much clearer than of those at the lake shore, and, as will be found in the following pages, susceptible of only one interpretation, and the former masses have the same surroundings as those of the latter. Excluding the opinions of previous writers and interpreting the common facts of a part of the formation by the facts common to the whole, an explanation totally different from that of Dr. Lawson must be assigned to the anorthosyte.

In the S. W. ¼ of sec. 10, T. 55–8, at the top of the northward facing bluff, 600 feet above the lake, are large masses of anorthosyte embedded in the black gabbro of the region. The black rock here forms a perpendicular wall one hundred feet high. The anorthosyte occurs only at the top of the ridge; it is surrounded and cut by the diabase. The contact between the two rocks is somewhat irregular and the anorthosyte has the appearance of large irregular masses, rather than that of a water-worn boulder or hilltop. Many of the large blocks have been separated from the enclosing rock and also broken in to smaller blocks, mainly through the action of recent ice in the cracks, and finally have fallen over the bluff. One block fifteen feet in diameter has been lifted partly out of its bed of diabase, leaving an irregular basin several feet deep, which was nearly full of water at the time. On the south slope of the same ridge in the S. E. ¼ of sec. 10, are several large masses of anorthosyte. These appeared as though they had been rolled down from the top of the ridge.

Both of the above occurrences are on the western extension of the range which has been mentioned in the following: "Be-

tween Beaver Bay and the Great Palisades are numerous feldspar masses, in the coast series, and inland from the shore a very short distance is a range of low hills made up of feldspar, with traprock on the flanks."* The Beaver river breaks through this range and precipitous bluffs of black olivine gabbro along both sides of the stream plainly show that this is the only rock forming the range at this place. Masses of anorthosyte of all sizes occur enclosed in the black rock. The flows of felsyte cover the gabbro and the anorthosyte. In the east ½ of sec. 1, T. 55–8, on the summit and the south slope of the ridge are several large masses of anorthosyte. The southern slope of the ridge is heavily wooded and the rock outcrops are for the greater part concealed. In ascending the ridge from the lake shore nearly to the top the occasional outcrops are black gabbro or diabase. The anorthorsyte at the top is cut and surrounded in numerous places by the black gabbro.

Toward the north, the ridge breaks off abruptly in precipices twenty-five to fifty feet high. The rock is always the black gabbro which continues in extensive outcrops north of here. In the N. E. ¼ of N. W. ¼ of sec. 12, T. 55–8, large irregular masses of anorthosyte are enclosed in the black gabbro, which forms a perpendicular wall fifty to a hundred feet high running at right angles to the trend of the ridge. The black rock was traced northwestward into the valley north of the ridge. This plainly shows that the mass of the ridge is made up of this rock, and that the anorthosyte here simply forms a mass, capping the black gabbro. Going east on the "old county road" the ridge just mentioned is crossed, and for several miles the road runs along the base of a northward facing precipice of black gabbro, which forms the northern side of the ridge.

There are several breaks in the ridge where good cross sections were obtained, viz., along the creeks in section 31, T. 56–7, sections 19 and 20, sections 17 and 16, and along the Baptism river in sections 4, 10 and 15. Along these sections are continuous outcrops of black gabbro having in some places a coarsely bedded appearance, but usually massive. Anorthosyte masses occur frequently at the top and on the south slope of the ridge. A number of these have fallen over the bluff into the valley on the north. In the S. E. ¼ of sec. 8, T. 56–7, the anorthosyte masses are as large as fifty to one one hun-

*N. H. Winchell, 9th Ann. Rept., p. 34, 1880.

dred feet thick and three to five hundred feet wide. in one case covering the surface for an eighth of a mile. The black gabbro cuts these masses, and forms the base of the ridge.

In the N. E. ¼ of S. E. ¼ of sec. 27 and the N. W. ¼ of S. W. ¼ of sec. 26, T. 56-8, is an oblong ridge, one fourth of a mile long and one eighth of a mile wide at the the top and three hundred feet above the surrounding country and six hundred feet above lake Superior. The upper half of this elevation is composed of anorthosyte resting upon a base of the black gabbro of the region, dikes of which cut the anorthosyte, which here is found to vary in mineral composition considerably more than in other localities. It is not a pure feldspar rock. A large part of the rock contains numerous dark areas of the ferro-magnesian minerals. The whole rock has the composition of the normal gabbro. Specimens 188*a* to *g* represent the different phases of the rock.

One half a mile northwest of this locality, in the S. E. ¼ of N. E. ¼ sec. 27, is Schaff's hill. The greater part of this hill is composed of dark diabase, which forms perpendicular walls on all sides of the hill and makes the ascent to the top very difficult. On top of the hill and near the southwestern edge is a mass of anorthoryte about five hundred feet square. This is the same pure feldspar rock which occurs at Beaver Bay. This outcrop, six hundred and twenty feet above and four miles from lake Superior, is the most distant outcrop of this rock from the lake. Other occurrences are in the N. E. ¼ of S. E. ¼ sec. 26, and the S. W. ¼ sec. 25, T. 56-8. At both of these localities there is no doubt that they are enclosed masses. In the latter place an irregular mass of anorthosyte seventy feet in diameter has been broken off from the neighboring diabase wall and lies near its original place in a tilted position.

After these occurrences of the anorthosyte were examined the most important exposures at Beaver Bay on the lake shore were again examined. All of these outcrops hold the same relation to the diabases and gabbros of this region as that held by the outcrops farther inland.

The occurrence at the cove below Split Rock point is of importance, and there exists a difference of opinion concerning it. All geologists agree that the smaller masses of anorthosyte are fragments included in the diabase. Various views have been expressed concerning the large masses.* The limited extent and the relations of the anorthosyte are apparently the same as observed elsewhere. In this locality the relations

*Bulletin No. 8., pp. 11-14.

of the different rocks are somewhat indistinct. Viewed in the light of the other occurrences of even greater extent, whose geological relations are undoubted, it is safe to place the rocks in this locality in the same position. The hypothetical section of the rocks at Split Rock point, given in Bulletin number 8, p. 12, in no way represents the relations of the anorthosyte to the later rock, as understood by the writer.

The mineralogical composition is not as constant as is stated in Bulletin No. 8. Attention has been called to this fact by Prof. Winchell* in the following note: "That some of the masses were not of pure feldspar rock, but contained in the usual proportions, the minerals augite and magnetite. * * * Thin sections have revealed in the feldspar boulders, however pure they may appear to the eye, small quantities of augite, and from these minute quantities there are all gradations to typically constituted gabbro." These statements the writer, after his extended observations, is able to confirm.

In addition to the above, attention may be called to the fact that in the majority of cases the original ferro-magnesian mineral has been altered to chlorite, often forming a pseudo-amygdaloidal structure. 188*f* in thin section shows this character. The most typical outcrop of the anorthosyte is the ridge in the S. E. ¼ sec. 27, T. 56-8. In this large mass all variations and gradations described from different isolated localities are readily seen. Specimens 188*a* to *g* from this ridge represent all the varieties, and may be taken as a typtical set of the anorthosyte of the lake Superior coast.

Sufficient evidence has been presented to show that the anorthosyte occurs *only as included masses* in the diabases and that it does not represent a pre-Keweenawan terrane existing *in situ* beneath the diabase. Conclusions based upon this assumption have therefore no value.

The petrographical characters are the same as those of the central part of the gabbro formation. Considering the gabbro as the intrusive and the diabases as the effusive portions of the same magma, it is easily seen that while the upper portion of the magma was solidified as the gabbro, in the interior of the mass large masses or aggregations of feldspar were separated. These solid masses floating around in the liquid magma were ejected with it and, being considerably lighter than the surrounding molten mass, floated near the surface and are therefore at present only found near the top of the first outburst of

*Bull. VIII, p. xviii.

diabase. Later, when some of this diabase was eroded, the feldspar knobs projected above the surrounding rocks and at the time of the later lava flows were covered up by the felsytes and other rocks of the red rock group. This explains the origin and present position as well as the domed and hummocky characters of the anorthosyte.

VIII. SUMMARY.

In the preceding pages the writer has attempted to show several points of interest to those who are working in the geology of the pre-Cambrian rocks. A brief review of the more important points advanced will not be out of place.

Snowbank lake area. The structure and some of the characters of the rocks north and west of the lake are given. The quartz porphyry, so common in the Keewatin, here has an unusually extensive developement. An augite granite is described, with an explanation of the local occurrence of augite granites in Minnesota. Additional evidence is given showing the derivation of the mica and hornblende schists from the Keewatin.

Actinolite magnetite schists from the eastern Mesabi. Description of the schists and their geological associates is given, showing their derivation from a rock containing an original iron carbonate. These schists were greatly affected by the gabbro. The recognition of the true character of these schists will establish an important analogical link between the Mesabi and the Penokee series. It is also shown that the so-called Pewabic quartzyte between Birch lake and Gunflint lake belongs to the middle member (iron-bearing) of the Animikie.

The gabbro. Several observations in the hitherto unexplored regions are recorded. Attention is called to the varying mineralogical phases of the gabbro showing that it is to be considered as an intrusive rather than an effusive.

The red rock. Augite syenite, quartz porphyry, felsyte, etc., are described from the vicinity of Greenwood lake. These rocks were traced into similar rocks on the shore of lake Superior. It is shown that nearly all of the red rock forms one prominent group. The Keweenawan rocks north of lake Superior are divided into the gabbro, diabase, red rock and the later dike groups.

The diabases. Under this group are included the fine grained gabbros and diabases immediately south of the main body of the red rock group. It is also suggested that the subdivisions

of the Keweenawan of Minnesota into the minor groups of Irving is impossible. The diabases are considered as the effusive equivalent of the gabbro.

The anorthosyte. Evidence is produced showing that the anorthosyte occurs only as included masses in the *diabases*. In mineralogical composition it is the same as the gabbro of which it was originally a part. The anorthosyte occurs near the top of the first outflow of the diabase group and afterwards it was also covered by the felsyte and diabase of the red rock group. The conclusions based upon the supposition of Lawson that the anorthosyte formed a pre-Keweenawan terrane are thus rendered valueless.

XIII.

LIST OF ROCK SAMPLES COLLECTED IN 1893

BY A. H. ELFTMAN.

The greater part of these specimens have been examined in thin section. The term "anorthosyte" is used to designate the pure feldspar rocks of the Keweenawan. These specimens are marked with white shellac figures with the letter E after the number.

1. Dioryte inclusion in granite. S. W. ¼ N. W. ¼ sec. 1, T. 62–12.
2. Schistose inclusion in granite. Same locality.
3. Contact of hornblende schist and granite. Same locality.
4. Porous condition of schists. Same locality.
5. Diabase dike. S. W. ¼ S. E. ¼ sec. 24, T. 62–12.
6. Granite near the preceding.
7. Lenticular hornblende mass in granite. N. E. ¼ S. E. ¼ sec. 25, T. 62–12.
8. Quartz dioryte inclusion in granite. 4 specimens. N. W. ¼ N. E. ¼ sec. 7, T. 62–11.
9. Granite. Same locality.

10A. Gneiss. Inclusions in granite. S. E. ¼ N. W. ¼ sec. 7, T. 62–11.

10B. Contact. Same locality.

11. Quartz dioryte inclusion in granite. S. E. ¼ S. E. ¼ sec. 12, T. 62–12.
12. Diabase dike. Same locality.
13. Dioryte. Same locality.
14. Fine grained granite. S. E. ¼ N. E. ¼ sec. 13, T. 62–12.
15. Coarse granite. Same locality.
16. Schistose dioryte. N. E. ¼ N. E. ¼ sec. 13, T. 62–12.
17. Hornblende inclusion in granite. From the point on White Iron lake in S. W. ¼ S. W. ¼ sec. 12, T. 62–12.
18. Hornblende schist. Same locality.
19. Dioryte. Same locality.

20. Quartz. 200 paces north of S. E. corner sec. 11, T. 62-12.
21. Granite. Same locality.
22. Magnetite vein cutting granite. Same locality.
23. Magnetite. Same locality.
24. Light red granite. N. E. ¼ N. E. ¼ sec. 14, T. 62-12.
25. Dark red granite, Same locality.
26. Weathered granite. Same locality.
27. Mica schist. S. W. ¼ N. E. ¼ sec. 35 T. 63-11.
28. Schist. N. E. ¼ N. W. ¼ sec. 2, T. 62-11.
29. Mica schist. Same locality.
30. Concretionary greenstone. N. E. ¼ N. E. ¼ sec. 17, T. 63-9.
31. Diabase. Same locality.
32. Schistose diabase. Same locality.
33. Diabase dikes. *a.* Coarse, *b.* fine grained. N. W. ¼ N. E. ¼ sec. 17, T. 63-9.
34. Talc schist. N. W. ¼ N. E. ¼ sec. 17, T. 63-9.
35. Jasper. S. W. ¼ S. W. ¼ sec. 1. T. 63-10.
36. Schistose diabase. One foot from contact with jasper. Same locality.
37. Diabase. Twenty feet from contact. Same locality.
38. Diabase. Forty feet from contact. Same locality.
39. Dioryte. S. W. ¼ N. W. ¼ sec. 31, T. 64-9.
40. Hornblende porphyry. S. W. ¼ S. W. ¼ sec. 1, T. 63-10.
41. Schistose greenstone. Same locality.
42. Concretions in greenstone. Same locality.
43. Hornblende porphyry. N. E. ¼ S. E. ¼ sec. 31, T. 63-9.
44. Conglomerate. N. W. ¼ S. E. ¼ sec. 31, T. 63-9.
45. Quartzless porphyry pebble in conglomerate. Same locality.
46. Laminated diabase. N. E. ¼ S. W. ¼ sec. 31, T. 64-9.
47. Matrix of conglomerate. Same locality.
48. Dioryte. Same locality.
49. A to E. Quartz porphyry. S. W. ¼ S. E. ¼ sec. 31, T. 64-9.
49. F and G. Weathered surface of the preceding.
50. Diabase. Same locality.
51. Contact of diabase and quartz porphyry. Same locality.
52. Jasper. N. W. ¼ S. W. ¼ sec. 32, T. 64-9.
53. Hornblende porphyry. Same locality.
54. Coarse dioryte. N. E. ¼ S. W. ¼ sec. 32, T. 64-9.
55 Quartzless porphyry. S. E. ¼ N. W. ¼ sec. 26, T. 64-9.
56. Granite cutting porphyry. Same locality.

57. Quartzless porphyry. Same locality.
58. Contact of schist and porphyry.
59. Quartzless porphyry. N. E. ¼ N. W. ¼ sec. 26, T. 64–9.
60. Quartz porphyry. N. E. ¼ S. W. ¼ sec. 23, T. 64–9.
61. Quartzless porphyry. S. E. ¼ S. W. ¼ sec. 23, T. 64–9.
62. Hornblende schist. N. W. ¼ S. E. ¼ sec. 23, T. 64–9.
63. Argillyte. S. W. ¼ S. E. ¼ sec. 34, T. 64–9.
64. Gabbro. N. E. ¼ S. W. ¼ sec. 4, T. 63–8.
65. Gabbro. (Iron ore near bottom of the beds). Same locality.
66. Gabbro. (Iron ore near the top). Same locality.
67. Fine grained gabbro in the ore bed. Same locality.
68. Keewatin schist inclosed in gabbro. Same locality.
69. Coarse weathered gabbro. Same locality.
70. Coarse gabbro. S. E. ¼ S. W. ¼ sec. 4, T. 63–8.
71. Gabbro, largely plagioclase. Same locality.
72A. Olivine gabbro. S. W. ¼ S. W. ¼ sec. 4, T. 63–8.
72B. Bedded olivine gabbro. Same locality.
73. Contact of olivine and coarse gabbro. Same locality.
74. Diabase. N. W. ¼ S. W. ¼ sec. 34, T. 64–8.
75. Iron ore. N. E. ¼ S. W. ¼ sec. 4, T. 63–8.
76. Anorthosyte. N. W. ¼ N. E. ¼ sec. 24, T. 63–9.
77. Feldspar from No. 76. Same locality.
78. Specimens showing weathering of the gabbro.
79. Diabasic anorthosyte. S. E. ¼ N. W. ¼ sec. 24, T. 63–9.
80. Shows large plagioclase crystal in No. 79.
81. Olivine gabbro. N. W. ¼ S. W. ¼ sec. 20, T. 63–8.
82. Coarse olivine gabbro. Same locality.
83. Transition of Nos. 81 and 82.
84. Olivine gabbro. Same locality.
85. Olivine gabbro. N. W. ¼ S. E. ¼ sec. 1, T. 62–9.
86. Intermediate between Nos. 85 and 87.
87. Olivine gabbro. N. E. ¼ S. W. ¼ sec, 1, T. 62–9.
88. Granite dike. S. E. ¼ S. W. ¼ sec. 1, T. 62–9.
89. Anorthosyte. S. E. ¼ S. W. ¼ sec. 1, T. 62–9.
90. Plagioclase crystals. N. W. ¼ of N. W. ¼ sec. 13, T. 63–8.
91. Plagioclase and diallage. Same locality.
92. Diallage. Same locality.
93. Olivine gabbro. S. E. corner sec. 1, T. 62–9.
94. Anorthosyte. N. W. ½ N. E. ¼ sec. 12, T. 62–9.
95. Olivine gabbro. N. W. ¼ S. W. ¼ sec. 8, T. 62–8.
96. Diallage. S. W. ¼ N. E. ¼ sec. 2, T. 62–9.
97. Gabbro. N. W. ¼ N. E. ¼ sec. 29, T. 63–9.
98. Fine grained gabbro. Same locality.

99. Gabbro. Same locality.
100. Foliated olivine gabbro. Same locality.
101. Olivine gabbro. Same locality.
102. Contact between Nos. 97 and 100. N. E. ¼ N. W. ¼ sec. 29, T. 63–9.
103. Contact showing biotite in gabbro. Some locality.
104. Olivine gabbro. N. W. ¼ N. E. ¼ sec. 21, T. 61–9.
105. Olivine gabbro. S. W. ¼ N. W. ¼ sec. 31, T. 62–9.
106. Olivine gabbro. N. W. ¼ S. E. ¼ sec. 7, T. 61–9.
107. Foliated diabasic gabbro. S. W. ¼ sec. 12, T. 61-10.
108. Fine grained olivine gabbro. Same locality.
109. Olivine gabbro. Same locality.
110. Foliated olivine gabbro. S. E. ¼ S. E. ¼ sec. 27, T. 62–10.
111. Bedded olivine gabbro. Same locality.
112. Olivine gabbro. N. W. ¼ S. E. ¼ sec. 27, T. 62–10.
113. Anorthosyte. Same locality.
114. Anorthosyte. 100 paces north of No. 113.
115. Anorthosyte. S. W. ¼ N. E. ¼ sec. 27, T. 62–10.
116. Plagioclase crystal in No. 115.
117. Olivine gabbro. S. W. ¼ S. W. ¼ sec. 15, T. 62–10.
118. Granite. N. E. ¼ N. E. ¼ sec. 25, T. 62–8.
119. Contact between gabbro and granite. Same locality.
120. Olivine gabbro. S. E. ¼ N. E. ¼ sec. 20, T. 62–10.
121. Coarse gabbro. 100 feet north of magnetite ore. N. W. ¼ S. E. ¼ sec. 30, T. 62–10.
122. Infiltrated quartz. S. E. ¼ S. E. ¼ sec. 30, T. 62–10.
123. Pyroxenyte. Same locality.
124. Quartz and gabbro. Same locality.
125A. Olivine. Same locality.
125B. Hornblende. Same locality.
126. Olivine gabbro. Muskrat lake. S. W. ¼ S. E. ¼ sec. 30, T. 62–10.
127. Olivine gabbro. Muskrat lake. S. E. ¼ S. E. ¼ sec. 30, T. 62–10.
128. Gabbro. S. E. ¼ S. W. ¼ sec. 29, T. 62–10.
129. Matrix of conglomerate. N. E. ¼ S. W. ¼ sec. 26, T. 64–9.
130. Dioryte. S. E. ¼ S. W. ¼ sec. 13, T. 64–9.
131A. Concretionary schistose diabase dike. N. E. corner sec. 28, T. 62–11.
131B. Contact of granite and dike.
132. Granite with part of dike adhering.
133. Granite. S. W. corner sec. 28, T. 62–11.

134. Coarse foliated hornblende granite. N. W. ¼ N. W. ¼ sec. 33, T. 62–11.
135. Gabbro boulder. N. ¼ post sec. 28, T. 62–11.
136. Granite. E. ¼ post sec. 32, T. 62–11.
137. Orthoclase crystals. Same locality.
138. Orthoclase crystals. N. E. ¼ N. E. ¼ sec. 28, T. 62–11.
139. Coarse gabbro. S. W. ¼ S. W. ¼ sec. 19, T. 61–11.
140. Diabase. Same locality.
141. Slate boulder. Sec. 24, T. 61–12.
142. Pyroxenyte. Same locality.
143. Gabbro. Same locality.
144. Gabbro with chalcopyrite. Same locality.
145. Magnetite, sec. 24, T. 61-12.
146. Olivine gabbro. N. W. ¼ sec. 31, T. 61-10.
147. Anorthosyte. N. E. ¼ S. W. ¼ sec. 36, T. 61-11.
148A. Anorthosyte. S. W. ¼ N. W. ¼ sec. 31, T. 61-10.
148B. Olivine and plagioclase segregations in gabbro. Same locality.
149A. Anorthosyte. Harris lake. N. W. ¼ sec. 26, T. 61-11.
149B. Olivine gabbro. Harris lake. N. E. ¼ sec. 27, T. 61-11.
150. Biotite gabbro. N. W. ¼ sec. 29, T. 61-11.
151A. Contact between feldspar and olivine segregations. N. E. ¼ N. E. ¼ sec. 6, T. 60-11.
151B. Laminated weathered surface of No. 151A.
151C. Diallage. Same locality.
152. Anorthosyte. N. W. ¼ S. W. ¼ sec. 8, T. 60-11.
153A. Olivine gabbro. N. ¼ post sec. 2, T. 60-10.
153B. Olivine gabbro. N. W. ¼ sec. 35, T. 61 10.
154. Anorthosyte. S. W. ¼ N. W. ¼ sec. 35, T. 61-10.
155. Olivine gabbro. N. ¼ post sec. 3, T. 60-10.
156. Olivine gabbro. N. E. ¼ N. E. ¼ sec. 4, T. 60-10.
157. Gabbro. S. W. ¼ sec. 4, T. 59-10.
158. Diallage. Harris lake. Sec. 26, T. 61-11.
159. Olivine gabbro. 100 paces west of N. E. corner sec. 1, T. 59-10.
160. Olivine gabbro. S. E. ¼ N. E. ¼ sec. 1, T, 59-10.
161. Gabbro. 500 paces S. of E. ¼ post sec. 1, T. 59-10.
162. Granite. Boot lake. S. W. ¼ N. E. ¼ sec. 21, T. 64-8.
163. Spotted talc schist. N. W. ¼ S. E. ¼ sec. 15, T. 64-8.
164. Spotted talc schist. N. E. ¼ S. W. ¼ sec. 22, T. 64-9.
165. Talc schist. Same locality.
166. Spotted schist. Same locality.

167. Schist with large orthoclase crystals. Same locality. Preceding 4 specimens are transitions from 164 to 167.
168. Quartzless porphyry. S. W. ¼ N. W. ¼ sec. 21, T. 64-8.
169. Ferruginous talc schist. S. E ¼ S. W. ¼ sec. 20, T. 64-9.
170. Gabbro. N. ½ part sec. 4, T. 60-8. [Lost.]
171A. Diabase. N. W. ¼ N. W. ¼ sec. 36, T. 60-8.
171B. Diabase. S. W. ¼ N. W. ¼ sec. 36, T. 60-8.
172. Black felsyte porphyry. N. ½ post sec. 31, T. 58-7.
173A. Red felsyte porphyry. Same locality.
173B. Weathered surface of No. 173A.
174. Laminated felsyte. Same locality.
175. Olivine gabbro. S. E. ¼ S. E. ¼ sec. 30, T. 59-10.
176. Hypersthene gabbro. S. E. ¼ sec. 32, T. 59-10.
177. Gabbro veins. S. E. ¼ sec. 19, T. 60-8.
178. Hypersthene gabbro. Greenwood lake. N. E. ¼ sec. 9, T. 58-10.
179A. Reddish gabbro. N. E. ¼ sec. 16, T. 58-10.
179B. Olivine gabbro. Same locality.
180. Augite syenite dike. Same locality.
181A to E. Felsyte. N. E. ¼ S. E. ¼ sec. 33, T. 58-10.
182. Felsyte porphyry. N. W. ¼ sec. 3, T. 57-10.
183. Diabase. N. W. ¼ sec. 3, T. 57-10.
184. Felsyte porphyry. S. E. ¼ S. E. ¼ sec. 1, T. 57-11.
185. Augite syenite. N. E. ¼ S. E. ¼ sec. 25. T. 58-10.
186. Augite syenite. 50 paces south of N. W. corner sec. 30, T. 58-10.
187. Gabbro. "Grandmother" hill. S. W. ¼ S. E. ¼ sec. 8, T. 57-13.
188. Anorthosyte. N. E. ¼ S. E. ¼ sec. 27, T. 56-8. *a* Light colored. *b* Shows fracture. *c* Dark colored, *d* Chlorite segregations. *e* Weathering. *f* Fine grained. Chlorite evenly distributed.
189. Gabbro cutting No. 188.
190. Anorthosyte, shows weathering and chlorite. Schaff's hill. S. W. ¼ N. E. ¼ sec. 27, T. 56-8.
191. Gabbro. Schaff's hill.
192. Diabase at top of hill. S. W. ¼ S. E. ¼ sec. 22, T. 56-8.
193. Diabase north base of hill.
194. Diabase. In river bed. N. W. ¼ S. E. ¼ sec. 22, T. 56-8.
195. Amygdaloidal diabase, laumontite, chlorite, calcite and quartz. Same locality.
196. Diabase porphyryte. S. W. ¼ S. E. ¼ sec. 22, T. 56-8.
197. Diabase. Same locality.

198A. Red mottled gabbro. S. E. ¼ S. W. ¼ sec. 34, T. 57-7.
198B. Diabase. S. E. ¼ S. E. ¼ sec. 34, T. 57-7.
199. Gabbro. S. E. ¼ S. W. ¼ sec. 27, T. 56-8.
200. Gabbro. S. E. ¼ S. W. ¼ sec. 11, T. 56-8.
201. Gabbro. N. E. ¼ N. E. ¼ sec. 13, T. 56 8.
202. Diabase. N. W. ¼ S. W. ¼ sec. 7, T. 56-7.
203. Diabase porphyryte. Same locality.
204. Gabbro containing plagioclase crystal 1 inch in diameter. N. E. ¼ sec. 6, T. 56 7.
205. Gabbro. N. W. ¼ N. E. ¼ sec. 6, T. 57-7.
206. Gabbro. S. E. ¼ sec. 19, T. 57-7.
207. Gabbro. N. W. ¼ N. W. ¼ sec. 25, T. 56-8.
208. Diabase. N. W. ¼ S. W. ¼ sec. 25, T. 56-8.
209. Anorthosyte. N. E. ¼ S. E. ¼ sec. 26, T. 56-8.
210. Red gabbro. N. E. ¼ S. W. ¼ sec. 25, T. 56-8.
211. Diabase. Bear lake, N. W. ¼ N. W. ¼ sec. 3. T. 55-8.
212. Diabase. N. E. ¼ N. W. ¼ sec. 3, T. 55-8.
213A. Amygdaloidal diabase porphyryte. On town road, ¼ mile south of N. E. corner sec. 3, T. 55-8.
213B. Same, one half mile south of the preceding.
214. Diabase. S. E. ¼ N. W. ¼ sec. 31, T. 56-8.
215. Gabbro. 50 paces south of N. W. corner sec. 15, T. 56-9.
216. Diabase porphyryte. N. E. ¼ N. E. ¼ sec. 9, T. 55-8.
217. Diabase. S. W. ¼ S. E. ¼ sec. 9, T. 55-8.
218. Diabase. S. E. ¼ S. E. ¼ sec. 9, T. 55-8.
219. Anorthosyte. S. E. ¼ S. W. ¼ sec. 10, T. 55-8.
220. Olivine gabbro. Second falls of Beaver river. N. W. ¼ S. W. ¼ sec. 12, T. 55-8.
221. Fine grained diabase. N. W. ¼ S. W. ¼ sec. 3, T. 55–8.
222. Amygdaloidal diabase. S. E. ¼ S. E. ¼ sec. 2, T. 55–8.
223. Gabbro. N. W. ¼ N. W. ¼ sec. 1, T. 55–8.
224. Anorthosyte. S. W. ¼ S. E. ¼ sec. 1, T. 55–8.
225. Augite syenite. S. W. ¼ sec. 5, T. 57–7.
226. Diabase. S. W. ¼ N. W. ¼ sec. 22, T. 57–7.
227. Olivine gabbro. W. ¼ post sec. 35, T. 55–11.
228. Diabase. S. W. ¼ N. E. ¼ sec. 33, T. 55–10.
229. Diabase. S. E. ¼ S. W. ¼ sec. 11, T. 55–10.
230. Anorthosyte boulder. Same locality.
231. Diabase. N. W. ¼ N. E. ¼ sec. 15, T. 55–10.
232. Diabase. N. W. ¼ N. W. ¼ sec, 23, T. 55–10.
233. Diabase. S. E. ¼ S. E. ¼ sec. 26, T. 53–11.
234. Ophitic gabbro. 100 paces north of S. E. corner sec. 27, T. 53–11.

235. Ophitic olivine gabbro. Same locality.
236. Contact between 235 and anorthosyte inclusion. Same locality.
237. Fine grained red gabbro. N. E. $\frac{1}{4}$ N. E. $\frac{1}{4}$ sec. 34, T. 53–11.
238. Diabase. N. W. $\frac{1}{4}$ S. W. $\frac{1}{4}$ sec. 12, T. 53–11.
239. Diabase. N. E. $\frac{1}{4}$ N. E. $\frac{1}{4}$ sec. 17, T. 53–11.
240. Diabase. S. W. $\frac{1}{4}$ N. W. $\frac{1}{4}$ sec. 8, T. 53–11.
241. Diabase with feldspar crystals. Same locality.
242. Compact felsyte. Railroad cut. N. E. $\frac{1}{4}$ sec. 21, T. 52–11.
243. Amygdaloidal diabase. Lake shore, sec. 21, T. 52–11.
244. Diabase. S. W. $\frac{1}{4}$ N. W. $\frac{1}{4}$ sec. 8, T. 53–11.
245. Amygdaloidal diabase containing laumontite, calcite, etc. Stewart river. S. W. $\frac{1}{4}$ N. E. $\frac{1}{4}$ sec. 29, T. 53–10.
246. Amygdaloidal diabase. From "copper mine." S. E. $\frac{1}{4}$ N. E. $\frac{1}{4}$ sec. 29, T. 53–11.
247. Fine grained phase of 246.
248. 4 specimens represent the rock below the amygdaloidal diabase, and form bed of the Stewart river. N. E. $\frac{1}{4}$ N. W. $\frac{1}{4}$ sec. 29, T. 53–10.
249. Diabase. Upper falls ("the slide") of Stewart river. N. W. $\frac{1}{4}$ S. W. $\frac{1}{4}$ sec. 20, T. 53-10.
250. Gabbro. S. W. $\frac{1}{4}$ S. W. $\frac{1}{4}$ sec. 15, T. 53-10.
251. Diabase. Mouth of Stewart river.
252. Gabbro. N. W. $\frac{1}{4}$ S. W. $\frac{1}{4}$ sec. 4, T. 53-10.
253. Diabase. Same locality.
254. Contact between Nos. 252 and 253.
255. Gabbro. N. W. $\frac{1}{4}$ sec. 6, T. 54-9.
256. Amygdaloidal diabase. Point below Split Rock river.
257. Diabase. First falls of Gooseberry river.
258A. Diabase. Flood bay. S. E. $\frac{1}{4}$ N. W. $\frac{1}{4}$ sec. 32, T. 53-10.
258B. Laminated diabase. Same locality.
259. Diabase. Rock cut two miles north of Highland. D. & I. R. railroad.
260. Diabase. N. W. corner sec. 12, T. 52-11.
261. Fine red mottled diabase. Lighthouse point at Two Harbors.
262. Diabase. Rock cut one mile north of Two Harbors.
263. A different phase of No. 262.
264. Diabase. One mile south of Cloquet.
265. Red rock boulder. Same locality.
266. Diabase. On old county road north of Great Palisades.
267. Quartzless porphyry. S. E. $\frac{1}{4}$ S. E. $\frac{1}{4}$ sec. 23, T. 64-9.
268. Granite. Same locality.

269. Schist. S. E. ¼ N. W ¼ sec. 24, T. 64-9.
270. Quartzless porphyry. N. E. ¼ S. E. ¼ sec. 19, T. 64-8.
271. Augite granite. N. W. ¼ S. W. ¼ sec. 20, T. 64-8.
272. Quartzless porphyry. S. W. ¼ N. W. ¼ sec 20, T. 64-8.
273. Granite. S. W. ¼ N. W. ¼ sec. 20, T. 64-8.
274. Siliceous schist. Boot lake. N. W. ¼ S. E. ¼ sec. 21, T. 64-8.
275. Granite. S. W. ¼ N. W. ¼ sec. 20, T. 64-8.
276. Matrix of conglomerate. N. E. ¼ S. E. ¼ sec. 22, T. 64-9.
277. Argillitic schist. Same locality.
278. Dioryte. N. E. ¼ S. W. ¼ sec. 28, T. 64–9.
279. Quartzless porphyry. Flask lake. S. E. ¼ S. E. ¼ sec. 28, T. 64-9.
280. Dioryte. Same locality.
281. Hornblende porphyry. S. W. ¼ N. W. ¼ sec. 31, T. 64–9.
282. Hornblende schist. Jasper lake, sec. 1, T. 63–10.
283. Hematite. S. W. ¼ S. E. ¼ sec, 1, T. 63–10.
284. Hornblende porphyry, Same locality.
285. Dioryte. N. W. ¼ S. W. ¼ sec. 26, T. 64–9.
286. Argillitic schist. N. E. ¼ S. W. ¼ sec. 26, T. 64–9.
287. Spotted talc schist. N. W. ¼ S. E. ¼ sec. 15, T. 64–8.
288. Diabase. Bed of Baptism river at the crossing of the old county road. S. E. ¼ sec. 4, T. 56-7.

MUSEUM ADDITIONS

SPECIMENS REGISTERED IN THE GENERAL

Serial No.	Obtained. When.	Obtained. Whence.	Name.	Number of specimens.
7947	Aug., 1891	A. E. Foote.....	Diablo canyon meteoric iron................	1
7948	"	"	Siliceous iron.....	1
7949	Feb., 1892	H. A. Ward.....	Fayette county, Texas, meteorite..........	1 slab
7950	Sept., 1892	Donation.......	Slag from the first iron furnace in America	3
7951	"	"	Iron " " " " " "	1
7952	Sept., 1893	Dr. A. Brezina..	Carlton meteorite, slab, etched............	1
7953	"	" ..	Bella Roca meteorite, slab, etched.........	1
7954	"	" ..	Crab Orchard meteorite, slab...............	1
7955	"	" ..	Mercedetas meteorite, slab, etched..... ...	1
7956	"	" ..	Duncan meteorite, slab, etched	1
7957	Feb., 1891	Presented	Magnetitic iron ore from crystalline schists	2
7958	"	"	Granite " " "	1
7959	....	....	Stratified volcanic dust (with casts of grasses)............................	1
7960	....	....	Ripple bedded volcanic dust (with pellets)	1
7961	July 3, 1892	Geol. Survey...	Beach stone..................	1
7962	....	" ...	Pyrite..................	2
7963	... .	" . .	Iron ore..	1
7965	....	....	Clinton iron are.........	1
7966	....	....	Glacial clay..................................	....
7967	Sep.20, 1889	Donated........	Sperrylite......	....
7968	Aug.7, 1892	Geol. Survey...	Quartzyte, light gray.......................	11
7969	J'ne 20.1893	" ...	Diabase, black................................	3
7970	"	" ...	" "	1
7971	Oct. 17.1893	" ...	Granite, gray, coarse	3
7972	"	" ...	" " " (with inclusions of black hornblende schist)	9
7973	Sep. 14,1893	" ...	Schist, sericitic, weathered, ferruginous ..	1
7974	J'ne 19,1893	" ...	Magnesian limestone, pyritiferous,—from a boulder......................	1
7975	Aug.3, 1293	" ..	Pebbles, red, of igneous rocks from N. E. Minnesota................................	10
7976	"	" ...	Lignite, fragments in modified drift	1
7977	Oct. 17,1893	" ...	Taconyte (20th Ann. Rep., p. 124), a fissile, slaty variety—from morainic drift......	3
7978	1892	" ..	Diabase, coarse, magnetic.............	1
7979	"	" ...	Gabbro, coarse..............................	1
7980	"	" ...	Diabase......................	2
7981	"	" ...	Granite, reddish..........	2
7982	"	" ...	" "	2
7983	"	" ...	Various rocks................................	6
7984	1893	" ...	Slate, black..................................	3

MINERALOGY AND LITHOLOGY.

MUSEUM SINCE THE LAST REPORT.

LOCALITY.	Formation.	COLLECTOR AND REMARKS.
Diablo canyon, Ariz.		A. E. Foote. Weight 12¾ oz.
" " "		Found in connection with 7047. 7¾ oz.
Fayette county, Tex		A large polished slab, 22x11 in.
Lynn, Mass		N. H. Winchell. From the old cinder piles.
" "		" " " " "
		By exchange. 249 gr.
Durango, Mex		" 210 gr
Cumberland Co, Tenn		" 55 gr.
		" 422 gr.
Maverick Co., Tex		" 118 gr.
N. of Long L., St. Louis Co., Minn	Vermilion	Hillberg and Brandine.
" " " "	"	" "
McPherson Co., Kan		J. A. Udden.
" "		" "
Morrison's bay, Pigeon Pt., Minn		N. H. Winchell.
Neenah, Wis	Galena	Chas. Schuchert.
1½ m. N. of Iron Ridge, Wis	Clinton	" "
" " "		" "
Menasha, Wis		" "
Sudbury, Ontario		Present by F. L. Sperry. [Kimberly).
N.W. side of Dam lake, Aitkin Co., near middle of W.½ of sec. 35, T. 46, R. 25	Pewabic	Warren Upham. (About 3¼ m. south of [the foregoing).
S.W.¼ of sec 9, T. 46, R. 25, Aitkin Co., western outcrop		" " (About 3 m. S. W. from
Same locality, eastern outcrop		" " These outcrops are about 20 rods apart, the 2d and smaller being N. E. from the first.
Hinsdale, D. & I. R. railroad, near center of S. ½ of sec. 8, T. 59, R. 14 W.; abandoned quarry		Warran Upham. (Forming the Giant's or "Mesabi" range; quarried here for the auditorium, Chicago.)
Same quarry with preceding		Warren Upham. (Boulders of similar granite, with such inclusions, are found rarely in southwestern Minnesota; for examples in Big Stone and Otter Tail counties, see vol. i, p. 525; and vol. ii, p. 551).
Near S. E. cor. of sec. 20, T. 46, R. 20, Carlton county		Warren Upham. (Close, W. of Kettle river, on road from Moose Lake station to Beaver. Aitkin county.)
Hickory P. O., sec. 26, T. 46, R. 27, Aitkin county	Gl. drift	Warren Upham. (Limestone boulders are very rare in this country.)
Shore of Sandy lake, Aitkin county, along road ½ m. south of dam	Mod. drift (Kame plateau gravel)	Warren Upham. (Forming the greater part of the gravel.)
Excavation for Sandy lake dam, Aitkin county	Mod. drift	Presented by Archibald Johnson, Superintendent of Construction. (Plentiful in a bed of sand and gravel below the level of the river.)
Mesaba station, D. & I. R. railroad, near S. E. cor. sec. 20, T. 59, R. 14	Gl. drift	Warren Upham. (Abundant in Knolly morainic drift here, and especially in belt crossed by railroad ¾-1¼ ms. S. E. of Mesaba.)
Cormorant island (3 m. N. E. of Rocky point) Lake of the Woods		J. E. Todd. No. 1.
Rocky point (near Gunderson's fishery) Lake of the Woods		J. E. Todd. No. 2.
Same locality		J. E. Todd. No. 3.
"		J. E. Todd. No. 4. (Sample of layer, vertical, 1-2 ft. thick at junction of gabbro and granite.)
"		J. E. Todd. No. 5. (Forming S. W. portion of Rocky point at Gunderson's.
Cormorant island, Lake of the Woods		J. E. Todd. No. 6.
Rapid River falls		J. E. Todd.

MUSEUM ADDITIONS

SPECIMENS REGISTERED IN THE GENERAL

Serial No.	Obtained.		Name.	Number of specimens.
	When.	Whence.		
7985	July 22, 1893	Geol. Survey...	Diabase	1
7986	"	" ...	Granite, biotitic	1
7987	1893	" ...	Mica schist, with pegmatite vein	6
7988	1893	" ...	Diabase	1
7989	July 15, 1893	" ...	Syenite, hornblendic	2
7990	1893	" ...	Mica schist with pegmatite vein	3
7991	"	" ...	Granite and diabase in contact	4
7992	"	" ...	Dioryte with feldspar vein	7
7993	"	" ...	Mica schist	1
7994	"	" ...	Granite, gray	1
7995	"	" ...	Gneiss, coarse	1
7996	"	" ...	Diabase	1
7997	"	" ...	Greenstone from boulder	2
7998	"	" ...	Limestone from boulder	1
7999	"	" ...	Various boulders	20
8000	"	" ...	Dioryte	1
8001	"	" ...	Dioryte, coarse	1
8002	"	" ...	Dioryte	1
8003	"	" ...	Dioryte	1
8004	"	" ...	Dioryte	1
8005	"	" ...	Limestone	1
8006	"	" ...	Greenstone with rounded quartzes	1
8007	"	" ...	Granite from dike in mica schist	1
8008	"	" ...	Graphic granite	12
8009	"	" ...	Gneiss, biotitic	1
8010	"	" ...	Granite, coarse, gray	1
8011	"	" ...	Granite with pegmatite vein	3
8012	"	" ...	Biotite granite, coarse	1
8013	"	" ...	" " fine	1
8014	"	" ...	Granite, garnetiferous	1
8015	"	" ...	" coarse, greenish	2
8016	"	" ...	Quartz vein rock	3
8017	"	Donation.......	Granite	2
8018	"	"	Mica schist, reddish	4
8019	"	"	Granite, gray, medium grained	1
8020	"	"	" reddish, rather coarse	2
8021	"	"	" coarse	3
8022	"	"	" biotitic	1
8023	"	"	Mica schist	1
8024	"	"	Granite	4
8025	"	"	Mica schist	3
8026	"	"	Doryte	1
8027	"	"	Anorthosyte	1
8028	"	"	Diabase, magnetitic	1
8029	"	"	Syenite, very fine grained, porphyritic	1
8030	"	"	Graywacke	3

MINERALOGY AND LITHOLOGY.

MUSEUM SINCE THE LAST REPORT.

LOCALITY.	Formation.	COLLECTOR AND REMARKS.
Big Fork river		J. E. Todd. (Locality B.)
" "		J. E. Todd. (Locality B.)
" "		J. E. Todd. (7 or 8 m. below junction of Big Fork and Sturgeon rivers.)
¼ m. E. of mouth of Rapid river.		J. E. Todd.
Rocky point, Lake of the Woods		" " [Elm Point.)
Long point. " "		" " (Long Point is also called
Lake of the Woods, S. shore		" " (Zipple's house, near mouth of Sand creek.)
" " " "		J. E. Todd. (Rock hummock 40 ft. high, ¼ m. S. W. of Zipple's, near the mouth of Sand creek or Winter Road river.)
Big Fork river, ½ m. below Sturgeon river		J. E. Todd.
Big Fork river, ½ m. below Sturgeon river		" "
Big Fork river, ½ m. below Sturgeon river		" "
Big Fork river, 4-5 m. below Sturgeon river		" " (Locality B.)
Barnesville, Minn.		" "
Mississippi river, 3-4 m. below L. Bemidji		" "
N. E. of Elbow lake, E. Hubbard county	Drift	" "
Big Fork river, T. 61-26		G. E. Culver. "First exposure on Big Fork." (Note B., p. 23.)
" " "		G. E. Culver. "First exposure on Big Fork." (Note B., p. 23.)
" " "		G. E. Culver. Probably from first exposure on Big Fork. (Note B., P. 23.)
" " "		G. E. Culver. Probably from first exposure on Big Fork. (Note B., p. 23.)
" " "		G. E. Culver. Probably from first exposure on Big Fork. (Note B., p. 23.)
" " "		G. E. Culver. Vein-like in form.
Big Fork river, ½ between Rice and Deer rivers		" " (Note B., p. 28.)
Big Fork river, ½ m. below Sturgeon river		" " (Note B., p. 29.)
Big Fork river, ½ m. below Sturgeon river		" " " "
Big Fork river, 1½ m. below Sturgeon river.		" " " "
Big Fork river, 10 m. below Big falls		" " " "
Between Sturgeon and Big Fork rivers, 25 m. below Big falls		G. E. Culver.
" "		" "
" "		" "
Big Fork river, 25 m. below Big falls		" " (Note B., p. 40).
" "		" " (" ").
" "		" " (" ").
S. line of sec. 33, 66-21		C. L. Chase. [N. of the granite.
W. line of sec. 18, 66-21		" " Mica schist is all along the
N. line of sec. 23, 66-21		" "
W. line of sec. 18, 66-21		" "
W. line (near N. edge) sec. 31, 66-21		" "
Sec. 9, 66-21		" " [granite.
" "		" " Schist is on the N. of the
Sec's. 22, 23 and 24, 66-23		" " Country is full of granite ridges, with intervening swamps; the granite runs N. E. and S. W.
Sec's 22, 23 and 24, 66-23		C. L. Chase. The schist lies to the N. of
S. E. ¼ S. E. ¼ sec. 4, 56-9		" " [the granite.
W. line sec. 5, 150 chs. N. of S. W. cor. T. 56-11		" " "Strike S. 70° W. Dip S. 70°".
N. line sec. 11, 56-11		" " About 5 chs. W. of river; about 25 chs. from E. corner.
S. W. ¼ S. W. ¼ sec. 15, 56-11		C. L. Chase. On river.
Sec. 20, 64-21		" "

MUSEUM ADDITIONS

SPECIMENS REGISTERED IN THE GENERAL

Serial No.	Obtained.		Name.	Number of specimens.
	When.	Whence.		
8031	1893	Donation......	Gabbro..........	1
8032	"	"	Diabase, fine grained..........................	1
8033	"	"	Syenite, very fine grained, porphyritic...	2

MUSEUM ADDITIONS

SPECIMENS REGISTERED IN THE GENERAL

Serial No.	Obtained.		Name.	Number of specimens.
	When.	Whence.		
8442	....	Geol. Survey...	Endoceras?	?
8443	....	" ...	"	"
8444	....	" ..	"	"
8445	....	" ..	....	"
8446	July, 1891	" ...	Rhychonella neenah Whit.....	2
8450	Sept., 1893	" ...	Aristerella nitidula Ulr......................	1
8451	"	" ...	Rhipidomella missouriensis...	6
8452	"	" ...	Productella pyxidata Hall..................	18
8453	"	" ...	Chonetes geniculatus White................	11
8454	"	" ...	Cyrtina acutirostris Shumard.............	11
8455	"	" ...	Ohonopterium effusum	?
8456	"	" ...	Productus sp.?	5
8457	"	" ...	Phillipsia sp.?................................	2
8458	"	" ...	Cryptoblastus melo O. & S...	2
8460	"	" ...	Spirifera pecullaris Shumard?.............	2
8461	"	" ...	Phillipsia sp.?...............................	2
8462	"	" ...	Platyceras sp.?	3
8463	"	" ...	Fish coprolite.....	1
8464	"	" ...	Pleurotomaria sp.?............	4
8465	"	" ...	Platyceras sp.?	1
8466	"	" ...	Zygospira? sp.?.........	14
8467	"	" ...	Cornulites carbonarius Gurley..............	1
8468	"	" ...	Palæacis enormis M. and W................	1
8469	"	" ...	Orthothetes lens.............................	6
8470	"	" ...	Euomphalus sp. ? (young of E. latus).......	2
8471	"	" ...	Leptæna rhomboidalis....................	3
8472	"	" ...	Zaphrentis ida A. Winchell.........	2
8473	"	" ...	Strophalosia scintilla...............	1
8474	"	" ...	Orthis testudinaria Dalman..........	12
8475	"	" ...	Fish teeth, gen. ? sp. ?........	5
8476	"	" ...	Zaphrentis calceola W. and W	2
8477	"	" ...	Spirifera marionensis Shumard.............	10
8478	"	" ...	Athyris hannibalensis Swallow............	3
8479	"	" ...	Spirorbis kinderhookensis Gurley.........	1
8480	"	" ...	Terebratula burlingtonensis White.........	5
8481	"	" ...	Chonetes ornata	6
8498	Aug., 1891	" ...	Hindia sphenroidalis Duncan.......	2
8499	"	" ...	Raufella filosa Ulrich.......	1
8500	"	" ...	Ischadites iowensis Owen..................	1
8505	"	" ...	Rafinesquina alternata Conrad............	1
8506	"	" ...	Orthis subquadrata Hall....................	3
8507	"	" ...	Strophomena filitexta Hall..........	1
8513	"	" ...	Orthis meedsi W. and S..........................	2
8514	"	" ...	Zygospisa uphami W. and S..................	5
8515	"	" ...	Platystrophia biforata Schlot..........	2
8516	"	" ..	Orthis ? subæquata var. gibbosa Billings..	1
8517	"	" ...	Orthis testudinaria var. meeki.............	1
8518	"	" ...	Rhynchotrema inæquivalvis...............	5
8519	"	" ...	Rhynchonella increbescens Hall	2
8520	"	" ...	Orthis subæquata var. perveta Conrad....	1

MINERALOGY AND LITHOLOGY.

MUSEUM SINCE THE LAST REPORT.

LOCALITY.	Formation.	COLLECTOR AND REMARKS.
N. E. ¼ N. E. ¼ sec. 4, 55-11	....	O. L. Chase. No. 8032 is in a wall 30 ft. high facing N. 50° E.; slopes S. 100 paces to the level of the ground. On the N. is No. 8031, making a small ridge E. and W., separated from the last by a ravine. No. 8033 is in a vein in No. 8031.
" "	....	
" "	....	

PALEONTOLOGY.

MUSEUM SINCE THE LAST REPORT.

LOCALITY.	Formation.	COLLECTOR AND REMARKS.
Decorah, Ia	Trenton limestone	Chas. Schuchert.
Minneapolis, Minn	" "	
Decorah. Ia	" "	Chas. Schuchert.
Hader, Minn	Galena..	Scofield and Schuchert.
Iron Ridge, Wis	Hudson River	Chas. Schuchert.
Chatfield, Minn	Trenton sh'l's	Presented by E. O. Ulrich. Vol. III, p. 545.
Louisiana, Mo	Lith.lim'st'ne	R. R. Rowley. By exchange.
" "	" "	" " " "
" "	" "	" " " "
" "	" "	" " " "
" "	" "	" " " "
" "	L. Burl. ch...	" " " "
" "	" ...	" " " "
" "	" ...	" " " "
" "	" ...	" " " "
" "	" ...	" " " "
" "	" ...	" " " "
" "	" ...	" " " "
" "	" ...	" " " "
" "	Lith.lim'st'ne	" " " "
" "	" "	" " " "
" "	" "	" " " "
" "	" "	" " " "
" "	" "	" " " "
" "	" "	" " " "
" "	" "	" " " "
" "	" "	" " " "
" "	" "	" " " "
Near Edgewood, Pike Co., Mo.	Clinton group	" " " "
Louisiana, Mo	?	" " " "
" "	L.Burl. chert.	" " " "
" "	Lith.lim'st'ne	" " " "
" "	" "	" " " "
" "	" "	" " " "
" "	L.Burl. chert.	" " " "
" "	Lith.lim'st'ne	" " " "
....	Niagara gr....	Scofield and Schuchert.
....	....	" "
....	....	" "
....	Hud. Riv. gr..	
....	Trenton sh'l's	
....	Galena shales	
....	"	
....	Trenton sh'l's	
....	Hud. Riv. gr.,	
....	Galena shale.	
....	Trenton shale	

MUSEUM ADDITIONS

SPECIMENS REGISTERED IN THE GENERAL

Serial No.	Obtained.		Name.	Number of specimens.
	When.	Whence.		
8540	July, 1891	Geol. Survey...	Conularia quadrata Walcott	...
8541	"	" ...	Monotrypella subquadrata	...
8548	Aug., 1891	" ...	Endoceras sp. undet	2
8549	"	" ...	"	1
8550	"	" ...	"	1
8551	"	" ...	" "	1
8556	May, 1879	" ...	Orthis biforata Schlot	2
8560	....	" ...	Chætetes petropolitanus Pander.	2
8561	....	" ...	Bucania	1
8562	....	" ...	Asaphus megistus Locke	1
8563	....	" ...	Cyclonema ventricosum Hall	2
8564	....	" ...	Chætetes corticans Nich	2
8565	....	" ...	Murchisonia gracilis Hall	1
8566	....	" ...	Chætetes delicatulus Nicholson	...
8567	....	" ...	Chætetes mammulatus Ed. and H	1
8568	....	" ...	Chætetes subpulchellus Nich.	1
8569	....	" ...	Heterocrinus heterodactylus Hall	1
8570	....	" ...	Cyclonema bilix Conrad	3
8571	....	" ...	Pleurotomaria umbilicata Hall	2
8572	....	" ...	Bellerophon bilobatus Sow.	3
8573	....	" ...	Chætetes onealli James	9
8474	....	" ...	Conchicolites corrugatus Nich	2
8575	....	" ..	Ortonia minor Nich	1
8576	....	" ...	Orthoceras byrnesi Miller	1
8577	....	" ...	Lichenocrinus crateriformis Hall	1
8578	....	" ...	Crinoid base	2
8579	....	" ...	Orthoceras	1
8580	....	" ...	Glyptocrinus decadactylus Hall	2
8581	....	" ...	Murchisonia	2
8582	....	" ...	Murchisonia bellicincta Hall	6
8583	....	" ..	Zygospira headi Bill	1
8584	....	" ...	Palæophyllum divaricans Nich	3
8585	....	" ...	Protaræa vetusta Hall	2
8586	....	" ...	Orthoceras	3
8587	....	" ...	Ortonia minor Nich	3
8588	....	" ...	Dalmanites carleyi Meek	1
8589	....	" ..	Constellaria antheloidea Hall	4
8590	....	" ...	Cyrtolites ornatus Conrad	3
8591	....	" ...	Chætetes frondosus Nich	3
8592	....	" ...	Chætetes rugosus Hall	6
8593	....	" ...	Chætetes fletcheri E. & H.	3
8594	....	" ...	Pleurotomaria ohioensis	1
8595	....	" ...	Stomatopora arachnoidea Hall	1
8596	....	" ...	Chætetes approximatus Nicholson.	7
8597	....	" ...	Chætetes jamesi Nich	5
8599	....	" ...	Orthoceras dyeri Miller	1
8600	....	" ...	Chætetes discoideus James.	1
8601	....	" ...	Chætetes clathratulus J. & N	3
8602	....	" ...	Chætetes gracilis James	6
8603	....	" ...	Chætetes dalei E. & H.	3
8604	....	" ...	Heterocrinus simplex Hall	3
8605	....	" ...	Chætetes ortoni Nich	1
8606	....	" ...	Calymene senaria Conrad	1
8607	....	" ...	Raphistoma lenticulare Emmons	3
8608	....	" ...	Protaræa vetusta Hall	1
8610	....	" ...	Columnaria alveolata Gold	2
8620	Aug., 1891	" ...	Lingula irene Billings	...
8623	....	....	Thaleops ovatus Conrad	1
8624	....	....	Toxaster comanchesi	1
8625	Jan., 1894	Wm. Johnston..	Elephas primigenius (tooth)	1
8626	....	Geol. Survey...	Vanuxemia decipiens Ulr	...
8627	....	" ...	Ctenodonta socialis Ulr	...
8628	....	" ...	" calvini Ulr	...

PALEONTOLOGY.

MUSEUM SINCE THE LAST REPORT.

Locality.	Formation.	Collector and Remarks.
Granger, Minn	Hud. Riv. gr..	Scofield and Schuchert.
Florence, Iowa	Cincinnati gr.	Chas. Schuchert.
Neenah, Wis	Galena	" "
Janesville, Wis	L'w'r blue b'd	" "
McGregor, Iowa	Trenton shale	" "
6 m. S. of Cannon Falls	Galena shale.	Scofield and Schuchert.
Mantorville, Minn.	Galena	Chas. Schuchert.
Cincinnati, O.	Hudson River	
"	" "	
"	" "	Chas. Schuchert.
"	" "	" "
"	" "	" "
"	" "	" "
Oxford, O	" "	" "
Cincinnati, O.	" "	" "
"	" "	" "
"	" "	" "
"	Cincinnati gr.	" "
"	Hudson River	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
Waynesville, O	" "	" "
Oxford, O.	" "	" "
"	" "	" "
Cincinnati, O.	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
"	" "	" "
Oxford, O.	Cincinnati gr.	" "
Graf, Iowa	" "	" "
Norwood, N. Y.		" "
Minneapolis, Minn	T'nt'n limest.	
Denison		[from the Sioux river.
Lincoln Co., S. D.	Drift	10 ft. below surface in gravel. 1000 ft.
Minneapolis, Minn	Lower Trenton limest..	C. L. Herrick.
Cannon Falls, Minn	Trenton sh'l's	E. O. Ulrich.
Graf, Iowa	Hud. River gr	Chas. Schuchert.

XV.

ADDITIONS TO THE LIBRARY SINCE THE REPORT FOR 1892.

The present list consists of the additions made from Dec. 1, 1893, to April 1, 1894.

A

Albany. Bull. State Museum, iii, No. 11, 1893.

B

Baltimore. Amer. Chem. Jour., xv, 7–8, 1893; xvi, 1–2, 1894.
Johns Hopkins Univ. Circulars, xiii, 108–110, 1894.
Belfast. Report and Proc. Belfast Nat. Hist. and Philosophical Soc., 1892–1893.
Berkeley. Bull. Dept. Geology Univ. of Calif., i, pp. 72–160, Dec., 1893.
Berlin. Deutschen Geologischen Gesells. Zeitschrift, xlv, No. 2, 1893.
Bern. Mitth. Naturf. Gesells., Nos. 1279–1304, 1892.
Boston. Proc. Boston Soc. Nat. Hist., xxvi, No. 1, 1892–93.
Braunschweig. Jahr. de Vereins für Naturwissenschaft, No. 7, 1889–90 and 1890–1891.

C

Cambridge. Appalachian Mountain Club, Appalachia, vii, No. 3, Mch., 1894. Register, 1894.
Peabody Acad. Science, Annual Reports, i–vi, 1869–1873.
Harvard College, Mus. Comp. Zool., Annual Rep. of Curator, 1892–93; Bull., xxv, Nos. 5–6, 1894.
Chicago. Univ. of Chicago, Jour. of Geology, i, Nos. 1–8, 1893; ii, Nos. 1–2, 1894.
Cincinnati. Jour. Cincinnati Soc. Nat. Hist., xvi, Nos. 1–4, 1893–1894.

D

Darmstadt. Mitth. Geol. Landesanstalt zu Darmstadt, i, No. 1, 1893.
Denver. Colorado Sci. Soc., ext. from Proc., 1893–1894.
Des Moines. Annual Rep. Iowa Geol. Survey, 1892.
Dresden. Jahr. des Vereins f. Erdkunde, xxiii, 1893.

E

Edinburgh. Trans. Edinburgh Geol. Soc., vi, No. 5, 1893.
Proc. Royal Soc. Edinburgh, xix, 1891–92.

G

Glasgow. Proc. Philosophical Soc. of Glasglow, xxiv, 1892–1893.
Good Hope. American Antiquarian, xv, No. 6, 1893; xvi, Nos. 1–2, 1894.
Göttingen. Konigl. Gesells. der Wissens. zu Gottingen, Nachrichten, 11–14, 1893.

H

Heidelberg. Mitth. der Geol. Landesanstalt, I Erganzung zum I Bande, 1893.

I

Iowa City. Bull. Laboratories of Nat. Hist. State Univ., ii, No. 4, 1893.

K

Kiel. University, 88 pamphlets, mostly inaugural dissertations.
Naturw. Vereins für Schleswig-Holstein, Schriften, ii, No. 2, 1877; vii, No. 2, 1891; x, No. 1, 1893.

L

Leipzig. Kong. Sach. der Wissenschaften zu Leipzig, Berichte, iv-vi, math.-phys. Classe., 1893.
Liverpool. Proc. Geol. Soc. Liverpool, vii, No. 1, 1892–93.

M

Madison. Proc. Wisconsin State Historical Society, xxi-xxxiv, 1875-1887; xli, 1893.
Meriden. Trans. Meriden Scientific Association, v, 1893.
Metz. Jahr. Vereins für Erdkunde zu Metz, xv, 1892–93.
Mexico. Memoires y Revista Sociedad Cientifica "Antonio Alzate," vii, Nos. 1–6, 1893–1894.
Milwaukee. Trans. Wisconsin Acad. Sciences, ix, No. 2, 1892-93.
Minneapolis. Agr'l Experiment Station Bulletins, xxix-xxx, Dec., 1893.
American Geologist, xiii, 1–3, 1894.
Moscow. Societé Imp. des Naturalistes de Moscou, Bulletins 1–3, 1893.
München. Bayerisches Industrie & -Gewerbeblatt, xxv, Nos. 48–52, 1893; nos. 1–6, 1894.

N

New York. American Geog. Soc. Bulletin, xxv, No. 4, pt. 1, Dec., 1893.
Memoirs Amer. Mus. Nat. Hist., i, No. 1, 1893;
Bull. Amer. Mus. Nat. Hist., v, 1893.
Annals N. Y. Acad. Sci., ii, Nos. 1-2 and 4; also 4 odd Nos., 1884–1885; viii, Nos. 1-3, 1893.
Trans. N. Y. Acad. Sci., i, Nos. 1-3, 5, 6-8, 1880–1881.
Nürnberg. Abhandlungen der Naturh. Gesell., x, No. 1, (Duplicate) 1892.

O

Ottawa. Catalogue of rocks at the Columbian Exposition, 1893.
Annual Rep. Geol. Sur. Canada, v, pts. 1-2, 1890-1891, with case of maps.

P

Paris. Soc. des Sci. Nat. de l'Ouest, Bulletin, iii, Nos. 2-3, 1893.

Philadelphia. Tenny's Geology for teachers, classes and private students, 1871.

Proc. Acad. Nat. Sci., Ser. 3, xxiii, pt. 2, 1893; Journal, Ser. 2, i-viii, 1847-1881.

American Naturalist, xxvii, Oct.-Dec., 1893; xxviii, Jan.-Mch., 1894.

Reports of Progress Geol. Sur. Pa., C. C. to Z, inclusive, 1875-1889.

R

Rio de Janiero. Archivos Museo Nacional de Rio de Janeiro, viii, 1892.

S

Sacramento. Annual Rep. State Mineralogist of California, xi, 1891-1892.

San Francisco. Proc. California Acad. of Sci., 2 Ser., iii, No. 2, 1893; occasional papers, iv, 1893.

Santiago. Actes de Société Scientifique du Chile, iii, Nos. 1-2, 1893.

St. Louis. Annual Report St. Louis Public Library, 1891-1892.

Stockholm. Handlingar der K. Svenska Vetenskaps-Akad., xiii-xvii, Nos. 2-4, 1888-1892; xviii, Nos. 2-4, 1893; also xii, Nos. 2-4, 1887.

Abhandlingar zu Sveriges Geologiska Undersokning, Ser. C., Nos. 112, 116-134, 1892-1893.

T

Tacoma. Proc. Tacoma Acad. Sci., Tacoma, Wash., "Is it Mt. Tacoma or Rainer?" Hon. Jas. Wickersham.

Topeka. Trans. Kansas Acad. of Science, xiii, 1891-1892.

Toronto. Annual Rep. Canadian Institute, v, 1892-1893.

Trans. Canadian Institute, iii, pts. 2, 6, 1893.

U

Upsala. Arsskrifpt Upsala Universitet, 1892.

W

Washington. U. S. Nat'l Museum, Bulletin No. 45, 1893; Proc. U. S. Nat'l Museum, xvi, Nos. 950-958, 963, 965, 967-974, 1893.

Smithsonian Report, 1891.

Z

Zurich. Naturf. Gesell. Neujahrsblatt, xcvi, 1894.

XVI.

THE EXHIBIT OF THE SURVEY AT THE COLUMBIAN EXPOSITION.

BY N. H. WINCHELL.

The Minnesota survey had no independent agency in the State's exhibit at the Columbian Exposition, but aided through correspondence with the state board of managers in every way that was feasible. The survey also prepared a series of typical rock samples, numbering 100, dressed to the usual museum size of 3 in. by 4 in., which were fully labelled and well shown in a suitable vertical wall case, the various specimens being secured in position by brass clamps screwed into the case so as to hold both labels and specimens in position. This suite included all the sedimentary formations, with some special phases, and most of the crystalline rocks.

The survey also exhibited twenty unpublished maps designed to show the physical features of the state. These were essentially the same series of maps as those exhibited at the New Orleans Industrial and Cotton Centennial Exposition at New Orleans in 1884, but after damage by fire at Pillsbury hall they had been redrawn, and in some particulars had been corrected in accordance with later information. The judges who examined the exhibits of the Mines and Mining building awarded a diploma to this set of rocks and maps. It is signed by George H. Williams.

At the New Orleans Exposition the Minnesota survey had a much larger exhibit. Whether any award was made for this exhibit is not known. That Exposition broke up in confusion, the committee of awards did not make known its conclusions, and the directors never carried out its determinations. The Minnesota State Commissioner's report, covering a detailed re-

port of the operations of the Minnesota survey, and of various other departments of the state exhibit, was never published, though filed with the governor.

At the Universal Exposition at Paris, in 1889, a set of the publications of the survey was on exhibition and received a bronze medal and a diploma.

In addition to the general award as above by the judges at the Columbian Exposition, special diplomas were awarded to Mr. Warren Upham and to Mr. Louis Ogaard for expert assistance in the preparation of the survey exhibit.

After the close of the Exposition the Board of State Managers of the Columbian Exposition decided to dispose of the State's exhibit in the Mines and Mining building by depositing it in the General Museum of the University, on condition that it should be re-erected in Minneapolis in the same form as it had at Chicago. This served as a nucleus about which were gathered numerous other exhibits, donated by individuals and by State Commissioners, the whole being designed to make a large addition to the University Museum, especially illustrative of economical geology. The whole collection, after shipment to Minneapolis, was stored in the Colosseum building on the University grounds, and was almost entirely ruined when the building was destroyed recently by fire. Fortunately, however, the above series of maps had been removed to Pillsbury hall a short time before the conflagration.

INDEX.

A

B

THE GEOLOGICAL

AND

NATURAL HISTORY SURVEY

OF MINNESOTA.

The Twenty-third Annual Report, for the Year 1894.

N. H. WINCHELL,
State Geologist.

MINNEAPOLIS:
HARRISON & SMITH, STATE PRINTERS.
1895.

THE GEOLOGICAL

AND

NATURAL HISTORY SURVEY

OF MINNESOTA.

The Twenty-third Annual Report, for the Year 1894.

N. H. WINCHELL,

State Geologist.

MINNEAPOLIS:
HARRISON & SMITH, STATE PRINTERS.
1895.

V. 683

The Survey

ADDRESS.

MINNEAPOLIS, MINN., Dec. 20, 1894.

To the President of the Board of Regents:

DEAR SIR—I have the honor and the pleasure of tendering herewith the twenty-third annual report of the Geological and Natural History Survey, so far as pertains to the progress made in the geological department thereof, accompanied by some statements respecting the General Museum and the library accessions.

Respectfully submitted,

N. H. WINCHELL,

State Geologist and Curator of the General Museum.

GEOLOGICAL CORPS.

N. H. Winchell	State Geologist
Warren Upham	Assistant Geologist
U. S. Grant	Assistant Geologist

SPECIAL ASSISTANTS IN 1894.

E. O. Ulrich	Paleontology
J. M. Clarke	Paleontology
H. V. Winchell	Economic Geology
H. B. Ayres	Mapping of Carlton Co.

CONTENTS.

CONTENTS.

CONTENTS.

ILLUSTRATIONS.

ERRATA:

Page 32, tenth line from bottom, for "district terrane" read distinct terrane.

Page 79, sixteenth line from top, for "$1,958.85" read $1,058.85.

Page 79, seventeenth line from top, for "$5,535.33" read $4,635.33.

Page 195, fifth line from bottom, for "∞P, $P\infty$" read $\infty P\infty$, P.

I.

SUMMARY STATEMENT.

The work of the year has consisted chiefly in the study and arrangement of field-notes and collateral data and the preliminary examination of some of the specimens collected. Some of the final maps and manuscripts have also been prepared. Contour lines, based on the barometic and other levels obtained by the survey, have been placed on most of the township plats. The geological boundaries having been, in the main, determined with sufficient exactness by the field work of 1893, it remains only to draft the final sheets and compare and adjust all the data for the final report. This is progressing as fast as possible. Prior to the final description of the formations, all the field specimens must be examined more carefully than it has yet been possible to do. This is a tedious and technical process in which chemical and microscopical methods are followed.

During the year considerable labor has been put on a reconsideration of the general classification of the rocks of the lake Superior region, involving the study of some more remote collateral questions. This has been done preparatory to the correct grouping and naming of our oldest formations. This labor is not yet finished, and will not be till the final report is completed, as it is a continuous and progressive development, which has such wide scope that all geologists, who are, or have been, at work on the rocks, are contributors to the result.

The economic development of important interests in the northern part of the state has been constantly observed and noted. This repeated appearance of new and interesting geologic features incident to such development tends to delay the progress of the work toward the closing up of the investigation. It becomes necessary to re-examine the localities where these new developments spring up in order to embrace the facts in the general discussion. The recent discovery of considerable quantities of gold in the vicinity of Rainy lake led to one of these new developments. The survey, while it is in

active progress, also incurs a certain obligation to examine and report upon such interests, in order to furnish to the public authentic information. Such information serves to correct the wild rumors that sometimes get started, and often prevents the waste of ill-guided exploration by directing would-be investors in the essentials of profitable enterprise. In the months of September and October an examination was made of this region by Dr. U. S. Grant and Mr. H. V. Winchell, and their joint report on the same is embraced in the following pages. The assays which have been made of specimens procured by them in the field warrant the statement that gold exists in the Rainy lake region, in some places in sufficient quantities for successful quartz mining. These localities are near the International boundary line, and mostly in Canadian territory. There are some encouraging locations within Minnesota territory. The interest that has been aroused on this subject has attracted many to the district, resulting in the creation of several townsites which have several hundred inhabitants, as well as drawing attention to the fine agricultural lands of the Rainy river valley, and to other natural resources.

Volume III of the final report is still in the printer's hands. It has been delayed in completion by several unavoidable causes, but principally by a change in plan as to the amount of paleontology it should contain. It was decided to embrace a report on the gasteropods and cephalopods of the Lower Silurian, with the necessary plates. This would so enlarge the volume that it was thought best to put it up in two "parts," and it will be so published. During the last year there have been published independently some of the chapters of this volume, viz.:

Chapter VII. The Lower Silurian Ostracoda of Minnesota. By *E. O. Ulrich*. Pp. 629-693, 4 plates; published July 24, 1894.

Chapter VIII. The Lower Silurian trilobites of Minnesota. By *John M. Clarke*. Pp. 694-759, with 82 figures in the text; published Sept. 27, 1894.

The twenty-second annual report has also been published. The collaborators on the survey have published elsewhere the following contributions, devoted mainly to the geology of the state and of the northwest.

The fishing banks between cape Cod and Newfoundland. *Warren Upham*. Amer. Jour. Sci., 3, vol. xlvii, pp. 123-129, Feb., 1894.

Diversity of the glacial drift along its boundary. *Warren Upham*. Ibid., 3, vol. xlvii, pp. 358-365, May, 1894.

British drift theories. *Warren Upham*. Amer. Geol., vol. xiii, pp. 275-279, April, 1894.

Tertiary and early Quaternary baseleveling in Minnesota, Manitoba and northwestward. *Warren Upham.* Ibid., vol. xiv, pp. 235-246, Oct., 1894.

Tertiary and Quaternary stream erosion in North America. (Abstract.) *Warren Upham.* Amer. Ass. Ad. Sci., vol. xlii, pp. 181-183, 1894.

Pleistocene climatic changes. *Warren Upham.* Geol. Mag., new ser., dec. 4, vol. i, pp. 340-349, Aug., 1894.

Wave-like progress of an epeirogenic uplift. *Warren Upham.* Journ. of Geol., vol. ii, pp. 383-395, May-June, 1894.

The epeirogenic theory of the causes of the ice age. *Warren Upham.* Glacialists' Mag., vol. i, pp. 211-217, May, 1894.

Quaternary time divisible in three periods, the Lafayette, the Glacial and Recent. *Warren Upham.* Amer. Nat., vol. xxviii, pp. 979-988, Dec., 1894.

Evidences of superglacial eskers in Illinois and northward. *Warren Upham.* Amer. Geol., vol. xiv, pp. 403-405, Dec., 1894.

Composite generic fundamenta. *John. M. Clarke.* Amer. Geol., vol. xiii, pp. 286-289, Apr., 1894.

American species of Autodetus, and some paramorphic shells from the Devonian. *John M. Clarke.* Amer. Geol., vol. xiii, pp. 327-335, May, 1894.

Early stages of Bactrites. *John M. Clarke.* Amer. Geol., vol. xiv, pp. 37-43, pl. 2. July, 1894.

Nanno, a new cephalopodan type. *John M. Clarke.* Amer Geol., vol. xiv, pp. 205-208, Oct., 1894.

Artesian water-supply for Minneapolis. *N. H. Winchell.* [A letter to the City Council]. In the official proceedings of the Council, and in the Evening Spectator, Minneapolis, Aug. 25, 1894.

The Columbian Exposition. Some special state exhibits of the crystal line rocks. *N. H. Winchell.* Amer. Geol., vol. xiv, pp. 108-113, Aug., 1894.

The origin of spheroidal basalt. *N. H. Winchell.* Amer. Geol., vol. xiv, pp. 321-326, Nov., 1894.

Sketch of Dr. John Locke. *N. H. Winchell.* Amer. Geol., vol. xiv, pp. 341-356, [portrait], Dec., 1894.

A new meteorite, Minnesota No. 1. *N. H. Winchell.* Amer. Geol., vol. xiv, p. 389, Dec., 1894.

A sketch of geological investigations in Minnesota. *N. H. Winchell.* Jour. of Geol., vol. ii, Nov., 1894.

The state of Minnesota. *U. S. Grant.* Compte Rendu de la 5me Session du Congres geologique international, pp. 302-311, Washington, 1893.

Although the years 1893 and 1894 have witnessed a general and severe financial depression, the development of the iron ores of the state has been unabated. The shipments during 1893 were 739,919 tons from the Mesabi range and 820,621 tons from the Vermilion range. For 1894 the Mesabi range pro- 1,790,000 tons and the Vermilion range about 1,000,000 tons. A more detailed statement is given on another page of this report.

II.

THE ORIGIN OF THE ARCHEAN GREENSTONES.

BY N. H. WINCHELL.

In the twentieth annual report the writer presented some "preliminary considerations as to the structures and origin of the crystalline rocks." In the progress of that discussion he had occasion to make reference (pp. 20-25) to the Archean greenstones. Attention was directed to their anomalous character, their stratigraphic position, and to the limited scope of the philosophy which assigns them to a changed condition of basic irruptives through the action of dynamic metamorphism.

In the further consideration of the same subject it became necessary to study more carefully the work of Dr. Geo. H. Williams, in his valuable contribution to the geology of the northwest, then lately published.*

The tendency of the conclusions reached by Dr. Williams is to refer the greenstones as a body to dynamic metamorphism of massive irruptive rocks. Some of the crucial issues of this investigation, as they appeared to the writer were brought out in that former discussion, which offered a preliminary dissent from this conclusion, and which presented the bearing of some important broad considerations which indicated in general a sedimentary origin for the mass of the greenstones. The writer has also briefly referred to this subject in a paper on the greenstone agglomerate at Ely, Minn.†

The following pages will be devoted to a critical examination of the published work of Dr. Williams, based mainly on the facts presented by himself, but partly on the writer's own acquaintance with the regions described by him.

---

*_The greenstone schist areas of the Menominee and Marquette regions of Michigan; a contribution to the subject of dynamic metamorphism in eruptive rocks_, by GEORGE HUNTINGTON WILLIAMS, with an introduction by ROLAND DUER IRVING. (Bulletin 62 of the U. S. Geological Survey, Washington, 1890, pp. 241, and 16 plates). Received by the writer March 5, 1891.

†The Kawishiwin agglomerate at Ely, Minn., Amer. Geol. vol. ix, pp. 359-368, 1892.

It was in April, 1893, that this review was begun by the writer. He has devoted to it such hours as have been free from other duties, at irregular intervals, until it has assumed the proportions of a chapter far beyond the magnitude which was contemplated. The writer is conscious that the work is one of the *chefs d'œuvres* of the U. S. Geological Survey, and that it has already had a powerful influence in directing the sentiment of all geologists who have not specially interested themselves in this question. It is not expected that this criticism will counteract that tendency to any important degree. It will require another similar treatise, prepared with equal ability from a different point of view, to effect that result. In the meantime, however, as the writer in the course of his study of the crystalline rocks of the state, comes upon this question, he is forced to consider it before he can proceed with his further studies. Not being ready to accept some of the leading conclusions reached by the author respecting the greenstones of the regions discussed, it appears to be necessary to present in some detail the objections, and the reasons therefor, which he entertains.

The greenstones are the *bete noire* of the geologists of the crystalline rocks, and he who attacks them should consider well the hazard before he lets fly his first sling. The work of the writer on these ambiguous rocks has been largely in the field, but supplemented with laboratory and library studies, and he has experienced some fluctuations in his views as to their origin from time to time as he received new evidence. At first disposed to class them among clastic rocks, the derivation of whose sediments he considered problematical and did not venture to inquire into, he was induced later by the preponderating testimony and judgment of microscopical lithologists, to theoretically group them as eruptive in order to justify what he thought a necessary postulate respecting some of their attendants. After further and prolonged examination in the field, accompanied by some studies of their microscopical structures—his own and those of others—he was compelled to return, in a large measure, to his original opinion. His present belief is, therefore, that the great bulk of the "greenstones" as an Archean terrane, ought to be classed as *pyro-clastic*, i. e., that they originated from eruptive agencies, as tuff and all kinds of volcanic debris sometimes very coarse, and were distributed and somewhat stratified by the waters of the ocean into which the materials fell. That there would have been, and that there is

evidence to show that there was, in conjunction with such volcanic outbursts, an occasional escape from the same vents, of liquid lava, he is quite ready to admit, but he considers these as subordinate features, and with great difficulty identifiable. He would reverse the main conclusion of Dr. Williams as to the comparative amounts of these two sorts.

With this brief statement of the point of view from which this review is written, and an acknowledgment of his indebtedness to Dr. Williams for many fruitful ideas, and of patriotic pride in the capacity which he has shown as an American geologist in the production of so thoughtful and learned research in this difficult field, the writer desires simply to call attention to some of the passages in the interpretation of facts and in the scope of the philosophy of the bulletin, which appear to be faulty, fundamentally, and therefore to impair materially the validity of the author's conclusions.

As to the interpretation of facts, it will be convenient to divide them into (a) megascopic, and (b) microscopic.

As to the author's use of the theory of "dynamic metamorphism," we shall present some considerations under the following divisions, viz: (a) dynamic metamorphism as a theory, calling attention to an essential difference between reconstructive metamorphism and a retrogressive mineral change such as shown by the greenstones and the green schists. (b) The greenstones as a geological terrane.

(a) MEGASCOPIC FACTS NOT NOTED OR MISINTERPRETED.

First and chiefest amongst the megascopic facts here to be mentioned is the wide and almost universal stratiform structure which can be seen in the greenstones of the lake Superior region. It is true that the author confines his discussion strictly to the Marquette and the Menominee regions, and is not presumably responsible for facts that are to be found in other parts of the region. It is reasonable, however, that an author who draws broad conclusions respecting a rock terrane which extends over many districts, should be held accountable to all the facts that may be found characteristic of that terrane throughout its extent. If the interpretation which he finds sufficient for the facts in the area which he examines be not sufficient to cover the essential facts pertaining to the same terrane in another part of the region, his conclusions are faulty and must be amended or abandoned. In this case shelter cannot be taken from this responsibility by suggesting that the

greenstone schist belts of the Archean in Minnesota, or of Canada, or even of Europe, are possibly not in the same stratigraphic series, and may therefore not have a similar origin and history, for the stratigraphic place of the Archean greenstones here discussed is well ascertained, and has been avouched to be the same not only throughout the northwestern states, but in European countries wherever their taxonomic place has lately been determined. They constitute the uppermost of the three grand stratigraphic divisions of the Archean.* This was involved in the final conclusion of Prof. Irving respecting this (Marquette) region (p. 19), and had before been announced distinctly by N. H. Winchell for the greenstones of the Archean in Minnesota.† However, whatever their stratigraphic position, or their age, the scope of the investigation is stated by Prof. Williams to be such as "to discover if possible the origin of the greenstone schists of the lake Superior region." (P. 31). This he enters upon, however, with an evident pre-conceived determination to make the investigation a contribution to the metamorphism of eruptive masses. (P. 30).

Now the general stratiform structure which these greenstones present, and their evident megascopic fragmental character can be seen in many places about Marquette and also quite distinctly at the Lower Quinnesec falls on the Menominee river Indeed, Prof. Williams himself, as noted by Prof. Irving in his introductory note (p. 23), ascribes the most of the greenstones of the Marquette area to a "surface origin," as contrasted with a deep-seated irruptive origin, their original condition having been that of a volcanic tuff, and Dr. Williams himself admits that the northern area of greenstone at Marquette is of sedimentary origin. In the Menominee area, where these rocks are described as exhibiting little or nothing that points to sedimentary, or surface, origin, is a large exposure of plainly fragmental rock. This fact was noted by Dr. M. E. Wadsworth in a recent report‡ in the following terms:

In this connection it may be well to correct a very striking error in Williams's work, in which he describes the transition of eruptive diabases into sericitic schists at the Lower Quinnesec falls. This error is apparently due to a failure to observe the well-marked conglomeratic structure of the rock on the Michigan side of the falls, which shows that the main

* MICHEL LEVY: Sur l'origine des terrains cristallins primitifs. Int.Cong. Geol., London meeting, 1888 (1891). Pp. 117-118.

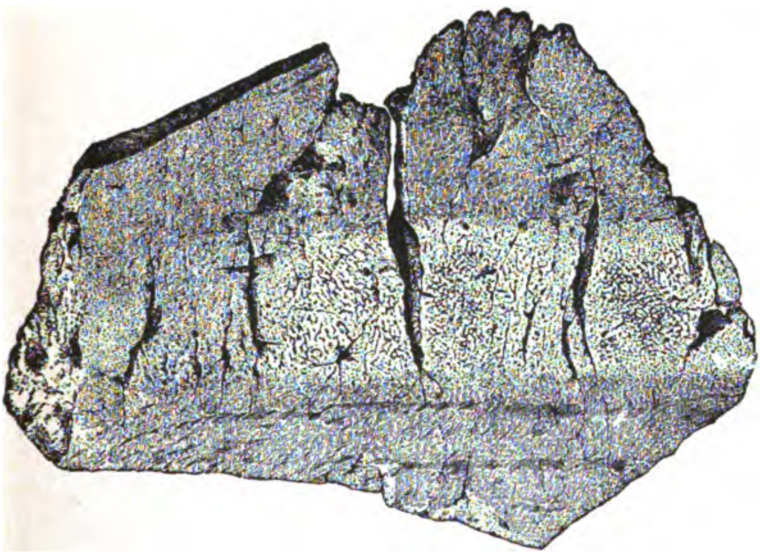
† Seventeenth Minnesota Report, pp. 43-44.

‡ Report of the State Board of Geological Survey of Michigan, 1892, p. 125.

rock at these falls is not a massive eruptive diabase or diorite, but a porodite (an old eruptive ash or conglomerate). * * * * Of the fragmental and conglomeratic nature of the rock no one can possibly doubt after studying it on the Michigan side, below the falls, and then tracing it back into the finer-grained and more compact part near the bridge. So good an observer as Williams could hardly have been led astray if he had examined the whole ground. A similar mistake seems to have occurred at the upper Quinnesec falls.

Under the guidance of Dr. Wadsworth a party of about twenty geologists, making an excursion from the late sessions of the Geological Society of America and of the American Association for the Advancement of Science, at Madison, 1893, visited and inspected the very place to which Dr. Wadsworth here refers. It is perhaps an eighth of a mile below the bridge (and the falls) on the left bank of the river. The trees have been removed and the rock is bare in many places. Scattered through the greenstone are numerous pebbles or small boulders, mainly of a nature similar to that of the rock embracing them, but sometimes much more siliceous. They are so numerous as to be in contact. Rudely stratified patches occur, and in one case a considerable outcrop of jaspilitic silica, with cloudings of color (red and purple), stands out to view. There seemed to be a general concord with the criticism made by Dr. Wadsworth. It was quite evident that here was a considerable area of plainly fragmental rock embraced in the greenstone of the Lower Quinnesec falls. Indeed the general appearance, not only here but at most points at these falls, observed by the writer on the occasion of this visit, was not unlike many occurrences which might be referred to in Minnesota. It is simply a question of weight of evidence—as between the eruptive characters and the fragmental. Confessedly Dr. Williams did not find any characters, even microscopic, of undoubted nature, in this rock which would ally it with certainty to the eruptives. But all the indistinct microscopic evidence adduced can plausibly be explained on the supposition of a fragmental origin for the whole. On the other hand the rock presents, as stated above, certain unmistakable evidences of original fragmental nature. These unquestionable evidences carry great weight as against certain hypothetical microscopic structures, which can easily be accounted for on the supposition of an original fragmental origin. Hence the rock at the Lower Quinnesec falls, or the greater part of it, can be classed with the tufaceous greenstones of the Marquette region which Dr. Williams allows to have had a sedimentary origin.

In connection with the interpretation of the megascopic features of these greenstones, Dr. Williams fails to note important distinctions. There are, *a priori*, various kinds of lamination, of banding, of schistose structure and of foliation, and they have different causes, but Dr. Williams refers to them all with indifference, and assigns them all to dynamic pressure and shearing. The only exception to this is seen in the case of the "banded greenstones" north of Marquette. Here the stratification is so evident that the author admits it is a sedimentary structure, although it resembles in many respects, and in its intimate structure grades into, that banding and schistosity which characterize the greenstones in other parts of the Marquette area regarded by the author as of dynamic origin. Some of these structures are certainly due to pressure and shearing, even in the rocks at the Lower Quinnesec falls, but some of the others are not. This general confusion, and lack of appreciation of these different structures, may be illustrated by the use made of the rock specimen figured on page 81, reproduced below.



Great stress is laid on the open transverse fissures or gashes which appear as in the figure on the weathering out of some of the secondary minerals on the face of the rock wall of the "gabbro ridge" of Brooks (dioryte ridge of Williams), but no mention whatever is made of the light colored band which

extends entirely across the specimen—as shown in the figure. To the eye of the writer these gashes may be due to glacial action or even to a later period of dynamic pressure. Similar gashes have been seen in the quartzytes of Minnesota,* and Dr. E. Andrews has seen somewhat similar markings in a similar rock on the northeastern shore of lake Huron.† In both cases they were unhesitatingly ascribed to the action of glaciers. However, whatever may be the cause of these "gashes," there seems to the writer but little doubt as to the cause of the light-colored band—it is plainly a sedimentary bed, and its existence can be referred to the action of the ocean which received presumably, and more or less distributed all its materials here, as well as the pebbles and other fragmental material seen in this rock a short distance below the falls.

This light colored band is certainly of the same nature and origin as other bands seen at the Lower Quinnesec falls, attributed by the author to dynamic shearing along certain parallel planes within the mass of the rock, and if he would be consistent he would be compelled to ascribe this band to the same cause. This explanation, however, would annul his argument for the dynamic origin of the gashes, since they stand at nearly right angles in the same rock mass.

Some other megascopic characters which evince a stratified sedimentary condition for the original rock are ascribed to frictional movement along certain planes and not along others. Indeed a plain banding which is quite like that seen in many of the fine graywackes and slates into which these greenstones gradually pass (in other places), and which is incontestably of sedimentary origin, is explained away as an effect of dynamic pressure and shearing There is plainly a greater fineness of grain, and a greater supply of quartz in some bands than in others, but this greater amount of quartz, and the coincident greater change in the associated minerals, are attributed to a greater activity of chemical change attendant on these planes of supposed greater slipping in the rock-mass. As an instance of the nature and the use made by the author of the microscopic phenomena to explain and annul what by most geologists would be taken as plain megascopic evidence of stratification by sedimentation, we give the following extract from page 87. The italics are the writer's:

*Final Report on the Geology of Minnesota. Vol. 1, p. 548.
†American Jour. Sci. (3), xxvi. 101.

Nos. 11004 and 11010, taken from either side of the above described band, [*i. e.* a "band of much lighter colored rock"] represent somewhat schistose varieties of it, which have been *produced by the action of pressure. That this is actually the case is admirably shown by a microscopic examination.* The hornblende of the original rock seems to have passed completely into a very pale and colorless chlorite. Saussurite, on the other hand, is less abundantly developed than in the more massive rock above described, and it is disposed in narrow veins or in small, irregular spots. The ilmenite has given its place to a dark gray substance resembling leucoxene. This is drawn out in stringers following the direction of the schistosity, and in the centre of these a yellow grain of rutile may sometimes be observed. Calcite is also present. The structure of the rock is completely different from that from which it is supposed to have been derived. It is now composed largely of a fine-grained ground-mass. This is made up of a microgranitic aggregate of minute grains of an unstriated substance resembling quartz but which, from its high specific gravity, is probably a feldspar.

We fail to see in these chemical and microscopic characters a proof of the application of pressure. If we were to attempt to explain them we do not see any difficulty in considering these schistose bands more siliceous and finer bands of tufaceous sedimentary materials. Being finer the mineral fragments were more changed from their originals prior to consolidation than were the minerals of the "more massive bands"; and again, being of finer grain, they took on the slaty schistosity under pressure more readily than the coarser and more massive strata. It is well known that a slaty cleavage, and hence a schistosity, which is a result of intersecting multiple cleavage. is frequently developed, in sedimentary graywackes, in the fine-grained strata, but does not appear in the coarser ones, although the coarser ones must have been subjected to the same pressure in the same directions and in equal amounts. The writer has seen this exemplified in a succession of layers made up of materials of differing fineness. It is a common fact exemplified in all roofing-slate quarries. We also cannot understand why a crushing or shearing pressure, presumed by the author in so many instances to account for a finer grain and for a degradational change in the concerned minerals, would not, with its predicated greater chemical activity, cause a chemical reconstruction of those minerals instead of a retrogression. Nor is it easy to see how, under dynamic action, such crushing and slipping could be made to pervade in some cases very thin layers or strata in the bulk of the rock, and in others should affect very large thicknesses (p. 105), and that these alternating coarse and fine kinds should be distinctly and persistently separable from each other in straight parallel planes extending for

many feet or even many rods, and until the exposed surfaces become hid from view. This feature of Dr. Williams' philosophy, however, will be examined separately. We here only allude to it as it is involved in his attempt to account for some of the magoscopic features by hypotheses somewhat novel and ill-founded. We are aware that during the last ten years great progress has been made in deciphering these "parallel structures" of rocks, and in assigning them to their causes. In this progress it has been shown that in many instances "certain parrallel structures" have been mistaken for sedimentary structure. Some extreme statements have, however, been made. to the effect that a parallel banded structure of differing composition and varying fineness of grain *is no evidence whatever of an original sedimentary origin.* But such wild affirmations, in the face of a uniform, worldwide experience and testimony to the contrary, carry with themselves their own refutation. It would hardly be more absurd to affirm that there is no such thing as a sedimentary structure. It remains to be seen whether some of the "banding" which petrographers have ascribed to other causes may not still have been primarily of sedimentary origin.

It is a singular fact, and one which is responsible for numerous errors of observation and interpretation, that stratification and cleavage are frequently, and prevailingly, parallel in the same rock mass. When they cross each other, as they do in some important areas in northeastern Minnesota, they are seen to diverge also in the proper characters by which they are separately identifiable, and each can be fully described by itself. But the well-nigh universal fact that they agree in direction is a significant index of a certain common history, pointing to a participation in some common experiences. Now this direction is usually broadly parallel to the ancient shore-lines of the adjacent land areas. The increments of land to the continent were marked by pressure and upheaval, which would not only be felt most markedly along the previous lines of weakness in the crust coincident with the strike of the sedimentation, but would at the same time produce a parallel schistosity in the rocks so raised above the sea. The latest of the Archean formations is the Kawishiwin and, as it shows both of these structures, it must have shared in this common experience. In other words, it must have been amenable to the same influences as an oceanic terrane, and it must therefore have had the widespread distribution of an oceanic terrane rather than the erratic and restricted distribution of an irruptive one.

In the description of the greenstones seen at the Lower Quinnesec falls Dr. Williams calls attention to some patches of porphyritic rock, and he is impressed with what he considers an anomalous condition of these feldspar crystals, viz., they do not show the degradational change, to that degree which prevails in the rest of the rock. He strives to account for this in the following way:

I know of no way of interpreting this phenomenon, substantiated by so many instances, except by supposing that the pressure which acts powerfully in stimulating chemical action in the solid rock, is relieved in the harder grains of a crushed band, since these are able to change their positions by slipping among the softer materials. * * * The occurrence of the freshest feldspar in the most crushed rock must be regarded as the rule. (P. 88.)

In another instance, in discussing certain acid rocks at Marquette (p. 150), the author finds both quartz and feldspar grains in a rock which has undergone such dynamic action. The former is stretched and broken, but the latter is fresh, rigid and unchanged, and does not show evidence of great pressure. Here also the general principle which above is found to pervade the greenstones when porphyritic, is subjected to the anomalous hypothesis that feldspar is more enduring under pressure than quartz. But it is hard to believe that the feldspar endured the shearing and elongating action when the quartz was thus crushed. Under the supposition that the large grains were "able to change their position by slipping amongst the softer materials," the query naturally arises, why could not the quartz grains as easily slip from their places and avoid the pressure as the angular feldspar grains? It is perhaps more probable that the quartzes were original and that the feldspars were produced by the chemical action incident to the later dynamic forces.

This porphyritic structure at the Quinnesec falls is not common. The mass of the rock is destitute of it. Its fortuitous and limited occurrence suggests that it is not an original structure of the rock. A porphyritic magma would be likely to be wholly, or at least widely, porphyritic on cooling—at least if it moved in such quantity as to produce the greenstones of the region. It is hence reasonable to suppose that the chemical activities were sufficiently "stimulated" in this greenstone mass, by the shearing movements to which it has been incontestibly subjected, after consolidation, to produce the sporadic porphyritic areas which it now manifests. This would allow not only the local partial recrystallization, but would also give

opportunity for any later disturbances to fracture to some extent the porphyritic feldspars, as described by the author, while still leaving them comparatively fresh or even building out their periphyries. It would also relieve the anomaly of supposing that feldspar, in some cases though not in all, substantially remains intact under such dynamic action as the author appeals to, and it would, further, account for the occurrence of these porphyritic feldspars, which in other places Dr. Williams seems to have determined to be albite (pp. 156, 157), prevailingly in those portions of the greenstone in which the greatest mechanical effect is observable, viz., in the fine and schistose areas. It is to be admitted that the author seems to have determined these crystals to be of labradorite. They would be expected to be of albite if of secondary origin, and outwardly they have a resemblance to albite. The physical characters which the author mentions are supposed to be diagnostic of labradorite (p. 88). The specific gravity agrees with labradorite, and the extinction angles on either side of the twinning line, being 12° to 20°, agree with those of labradorite, which, according to Rosenbusch, affords extinction angles of 5° to 27°. This anomalous preservation of feldspars in the midst of what is regarded by the author as the most crushed and "metamorphosed" of the greenstones, *i. e.*, in the fine banded schists below the falls, is mentioned at several places. (See pp. 92 and 93.)

The author describes (p. 92) ellipsoidal, or lenticular, masses of non-schistose rock about which the schists appear to wind, enclosing them entirely. Although he does not so state, we infer that the direction of the fibrous structure of the schists is constantly parallel to the outer surfaces of these ellipsoidal masses. The writer has observed this to be the fact in several instances. The author describes the outermost of these envelopes as a "typical chlorite schist" in which alternating and interlacing areas of pale green chlorite may be distinguished in a fine quartz-albite mosaic. He takes these minerals to be the product of the same mysterious agent (dynamic metamorphism) which is appealed to to explain a similar mosaic in the banded schists—the same also as is presumed to have caused the parallel banding which has widely been taken for sedimentary structure. It appears, however, that there is a curious anomaly in thus appealing to "pressure" to produce such a variety of effects. If pressure caused the parallel banding of the adjacent schists, as presumed by the author, (which we hope the reader will not confound with schistose structure), how can

the same pressure produce at the same time a straight banding and a schistose structure which surrounds in parallel arrangement the periphyry of a lenticular mass and not only one, but many lenticular masses? Why should these ellipsoidal cores under the action of pressure be seggregated from the mass and surrounded by a finer rock arranged in schistose structure parallel to their periphyries, while they themselves show no such structure? They are largely decayed within, it is true, and have the grain of the surrounding rock mass in general. The mysterious agent then must have penetrated them thoroughly on the hypothesis of the author. It remains to account for this anomalous action of this agent. If, on the other hand, this be considered an agglomeratic portion of rapidly accumulating tufaceous sediment, received into an ocean heated perhaps by proximity to volcanic vents, and it be admitted that by the solvent action of its waters these sediments were changed mineralogically to about what they now appear to be, the finer and more siliceous parts of the residue, after oceanic levigation being allowed to lodge in the interstices between the coarser masses, surrounding them often in shells, as it were, of finer materials, and then the whole allowed to consolidate, and to experience the history which followed, what features, we may ask, would such a mass present after some pressure and stretching, which are not found in this rock by Prof. Williams?

The criticisms which have now been made of Prof. Williams' discussion of the megascopic features at the Lower Quinnesec falls, may in the main, be applied to his discussion of the same features at the Upper Quinnesec falls, as well as those at Sturgeon falls, for, as shown by him, the regions examined have a great similarity. The characters brought out at the latter place are particularly suggestive of fragmental origin (p. 71), viz: The structure of the rock is irregularly granular, none of the components being in any degree idiomorphic. Frequent and abrupt changes in the coarseness of the grain are observable. Colorless chlorite and zoisite are mixed indiscriminately, and often a mosaic of quartz and epidote, or of quartz and albite, composes the greater part of the finer-grained portion of the rock, or of the schists into which the coarser rock graduates, while the fragments of feldspar are seen to be broken and battered, and for the most part changed to sericite or calcite. These signs of fragmental origin we can perhaps attribute to the powerful solvent action of the Archean ocean. They are such as are ordinarily attributed to weathering, when they

are found to characterize, under known mechanical and chemical exigencies, rocks of this character exposed to present atmospheric forces, and we have no reason to exempt Archean time from those effects of atmospheric action which we are familiar with at the present.*

Continuing the consideration of the magascopic characters which seem to have been omitted or misinterpreted by Dr. Williams, we may follow his course of investigation from the Menominee valley to the Marquette region. Here he divides the greenstone area into four parts; the eastern, western, northern and the Deer lake areas. The rocks of the northern part of the "eastern" area are so plainly banded by sedimentation that he concludes that they are derived from volcanic tuffs. The southern part, though widely characterized by a fine almost aphanitic grain and by what he designated, in the case of the Menominee greenstones, as "spheroidal parting," and though he gives no description indicating how they are related to the rocks of the northern part, he considers to be altered eruptive rocks. It might be stated here that the two grade into each other by imperceptible degrees, passing through a siliceous and hematitic phase, named *Eureka beds* by Dr. Romiger, in which some iron ore has been mined, all belonging to the same greenstone series, and that further west, on the pinching out of the siliceous, or jaspilyte band, the two parts become indistinguishable, blending into one, in the manner represented on the map of Dr. Romiger, and in the manner in which such jaspilyte lenses rise and disappear along the strike in the greenstones of Minnesota. Whatever origin may be assigned to the northern part of the Marquette area, it is difficult, if not impossible, to divorce it from the origin assignable to the southern.

*Since the foregoing was written Prof. Williams has died. On resuming this study it is our first impulse to render to his memory some tribute expressive of the sense of loss which, in company with all American geologists, we experience in the sudden decease of one of our number when in the prime of his ability and activity. At 38 years of age Dr. Williams seemed to promise many years of active geological work. His brilliant career at Johns Hopkins University bespoke for the literature of American geology in the near future many and valuable contributions from his laboratory. Largely through his energy have the petrographical methods of Europe, and especially those of Germany, been introduced into America—greatly to the enrichment of our geological knowledge. He was not simply a petrographer, but a geologist of broad culture and grasp. who was as ready to apply his microscopic data to questions of greater scope as he was to discover the data. His occasional contributions to the geology of Maryland and of the Appalachians constitute some of the epochal steps of the geology of eastern America. Personally Dr. Willams was of courteous and engaging address, professionally obliging to all, socially making friends of all acquaintances, a ready and rapid speaker, a clear thinker and a beloved teacher. American geology has had but few his peer.

The "western" area of the greenstone is immediately in the line of strike of the southern part of the "eastern" area, and is continuously traceable from it. He also calls it the Negaunee area. He considers the greenstones of this area to resemble those of the southern part of the Marquette area. In the very center of this area, however, he found (p. 175) a remarkable fragmental rock, being a conglomerate resembling the "slate conglomerates" of the Canadian geologists and the Ogishke conglomerate of Minnesota. Impressed with the evidence of fragmental origin he frankly acknowledges that this rock, whose extension in no direction does he seem to have traced out, it is impossible to assign to any other than a fragmental origin and, although he here finds the same "spheroidal parting" as seen in the greenstones of the northern Marquette area, and the same kind of light-green aphanitic greenstone, he does not see any reason to assign the two rocks to the same cause. Nor does he attempt to explain in what way or at what place this fragmental greenstone can be separated from the other greenstones of the area. The acid masses embraced in this conglomerate are supposed by Dr. Williams to have been ejected by volcanic explosions in the midst of much basic ash, torn from the ducts through which the basic matter was discharged. It appears to the writer that the existence of this fragmental rock in this area of greenstone thus admitted by Dr. Williams, will be found fatal to the principal conclusion of the author touching the Negaunee area, for these conglomerates have been found to pervade the greenstones everywhere, and to fade out into them on all sides.

The greenstones of the "northern" area are "striped and banded" in the same manner as those of the northern part of the Marquette area, and are hence supposed to have been originally volcanic tuffs. In one of these, however, which he still seems inclined to have considered a massive rock originally, are porphyritic crystals of hornblende, recalling a green porphyrite schist found in northern Minnesota which has been classed with fragmental rocks after careful study by Dr. U. S. Grant.* Indeed, the general *tout ensemble* of these green schistose rocks closely compares with those about Kekequabic and Fall lakes in Minnesota, both of which have been pronounced fragmental on microscopic evidence.

* Twenty-first Minnesota report, pp. 23-27.

Still further west, in the same general belt of greenstones as the Marquette and Negaunee areas, is the Deer lake area. Throughout this whole greenstone belt is a uniformity of topography, and a constancy of outward lithology which implies to the observant geologist a unity of geological origin and structure —a fact which could also be said to extend many miles further west. In the Deer lake area, to which the author's attention was directed by Dr. Irving, this greenstone contains many fragmental rounded forms, some of them being felsitic, but most of them of some form of greenstone. Here also, according to Irving, are indistinct traces of oceanic sedimentary structure. Dr. Williams styles these rocks "green schists and agglomerates," and welcomes the fragmental characters as confirmatory of the conclusions he reached respecting the banded greenstones of the northern part of the Marquette area, although here the banded structure is almost wanting. Here, also, the acid masses are thought by the author to be referable to some volcanic ejection by which fragments were torn from the walls of the ducts through which the more volumnious basic materials were discharged.

It appears then that the greenstone areas examined by Dr. Williams have prevailingly fragmental characters. This is apparent from the descriptions if not from the general conclusions he has given. The only exceptions are, (1) the Menominee area, and, (2) the southern part of the eastern area at Marquette. Still even in the Menominee area he allows certain portions to have had a fragmental origin, viz., at Four-Foot falls and at the Upper Twin falls, pp. 124, 132.

He puts the whole of the northern Marquette area, the northern part of the eastern area at Marquette, the Deer lake area and a part of the Negaunee area (which part cannot easily be separated from the rest of the Negaunee area), amongst the volcanic tuffs which bear unimpeachable proofs of sedimentation, and, as has already been stated, an important area of evidently fragmental rock occurs in the Menominee area at the Lower Quinnesec falls, and cannot there be distinguished geographically from the rest of the Menominee greenstone. Another is reported by the author at the Upper Twin falls (p. 133.)

To a geologist who has traveled over these greenstones for many miles, and for many days of many seasons, this result is not at all surprising, for one of their most frequently recurring phenomena is a fragmental and a conglomeratic composition, a feature which goes so far sometimes as to make the rock

change to a siliceous porodyte with little or no trace of the ferromagnesian minerals remaining. It is such fluctuations, which occur both gradually and sporadically, that have caused the writer, when he has studied them in the field, to doubt the original massive character of any of them. It is hard to understand how such wide-spread fragmental characters could pervade a great formation, and yet that it could be properly classed broadly as an original massive rock changed to its present features by subsequent metamorphism. Instead of throwing the burden of proof, as to origin, upon the fragmental theory, when the megascopic characters become uncertain, with an assumption in favor of the irruptive theory, it seems to the writer that this burden lies upon the advocates of the irruptive hypothesis, and that the preponderance of evidence, from a megascopic point of view, is strongly in favor of a sedimentary origin of all such ambiguous greenstones.

In further discussion of the megascopic characters it is necessary to call attention to the confusion into which Dr. Williams seems to have fallen in the use of terms denoting megascopic structures. The writer has elsewhere* called attention to the variety of structures which are found in the crystalline massive rocks, and to the necessity of clear definitions for the terms applied to them. It is when clear ideas of these structures and their possible causes do not exist in the mind of the geologist that he is led to generalizations which embrace them all, or several of them, incorrectly. The point of view from which he approaches their discussion also inclines him favorably toward the abandonment of distinctions which ought to be carefully noticed. These truths are exemplified by some of the sentences of this bulletin. The following may be noted:

On p. 168 dykes are called "bands" of coarser materials.

On p. 192 the coarser layers of what some have considered sedimentary stratification are called "bands."

On p. 171 *et passim*, a schistose structure is called a "foliation."

On p. 179 a slaty cleavage is called a foliation. See also p. 202.

On p. 179 a quarzyte lying between two conglomerates and dipping steeply in conformity with them toward the south, is denied the structure of stratification and is said rather to be "foliated" by pressure.

---

* Twentieth Report of the Minnesota Survey." The crystalline rocks; some preliminary considerations as to their structures and origin." 1891 (1893).

On p. 110 a banded structure, consisting of gneiss alternating with green schist, is described, and a distinction is drawn between it and a schistose structure which is said to sometimes pervade the gneiss. But on p. 110 the banded structure and the schistose are confounded in one sentence as the same, and due to the same cause, viz., "The schistose or banded structure of these rocks, when such exists, is a secondary feature, produced by the same dynamic agencies which rendered the greenstones themselves schistose." The shifting of the name here, however, does not destroy the sense. It only shows a looseness of the use of these terms. Many such cases could be pointed out, viz., pp. 40, 44, 45, 82.

In many places the term "parallel arrangement" is employed. It seems to be applicable to various structures, and is made to cover several. On p. 149-50 it is used to express the arrangement of new crystallization products which give rise to a gneissic or "flaser" structure, produced by pressure. On p. 157 it indicates the disposition of microscopic hornblendes. On the other hand, it is applied to many macro-structures, and in some cases without definition. It is obvious that in many such cases the reader is wholly at a loss to comprehend the idea designed to be conveyed by the author when it is not defined in the context. This seems to indicate that all, or nearly all, the "parallel" arrangements are assignable, in the mind of the author, to the same cause, and that it matters little whether the specific structure under consideration be defined carefully or not. Nothing will illustrate this more completely than a single quotation. On p. 201 the author gives his idea of macrostructural metamorphism, and says:

> This embraces all modifications in the structure of the massive rocks produced by dynamic agencies and plainly visible to the unaided eye. Such changes consist, for the most part, in the production of a banding, foliation, or schistose structure which tend to make the eruptive rocks resemble stratified deposits. They are a secondary feature and must be correlated with the slaty cleavage, not with the original bedding of sediments.

The author lays great stress on the occasional divergence of the schistose bands, which appear in the greenstones at the Upper Twin falls (p. 132), from the normal and usual direction for the region, and argues from this divergence that the banding cannot be due to sedimentary structure. He infers therefore that it must have been due to crushing pressure acting locally in different directions and that no part of the banding seen there, however much it resembles that banding at Mar-

quette which he acknowledges is caused by sedimentation, can be referred to sedimentary action. But this argument would prove too much, for it can be applied to all parts of the greenstone terrane. There is nothing more evident in the greenstones in the region of Tower, Minnesota, than the divergence of sedimentation banding from the normal direction there prevalent. This is so common that it involves not only the green schists but the sericitic schists and the graywackes and jaspilytes,—and even the argillitic slates into which the chloritic schists gradually pass. Some years ago the writer employed this common fact to disprove the eruptive origin of the jaspilytes at Tower.* Such sudden divergences of the jaspilyte beds from the prevailing direction had been presumed to prove the eruptive origin of the jaspilyte. On the contrary it was found that, along with all the sedimentary rocks of the vicinity the jaspilyte had been broken, and the several strata had been thrust amongst the neighboring beds and made to hold various angles with the direction of the prevalent strike. Such features were illustrated in the report referred to. They proved, on the argument appealed to for the jaspilyte, that the argillytes and the graywackes must also have had an eruptive origin, thus reducing the argument to an absurdity. This consideration taken with the discovery made by Dr. Williams and reported by him on p. 133, that one of these bands showing such contrast at the Upper Twin falls was made up of fragmental materials, certainly goes far toward putting a negative upon the general conclusion of the author as to the nature of these fine-grained bands.

Before closing the discussion of the megascopic evidence brought forward by the author, it may be profitable to present in a summary form the results that seem to be derivable from this part of the examination. Employing only the facts and interpretations which are presented in the bulletin, the two kinds of rocks described by the author, *i. e.*, those that he presumes to have been massive and those which he finds to have been fragmental, are found to exhibit the following features in common. This comparison is not intended to involve those intrusive rocks, of later date than the greenstone formation, which are found everywhere amongst the Archean terranes, and which the author also describes in this bulletin. Only one acquainted with the region can distinguish, sometimes, whether

*Fifteenth Report of the Minnesota Survey, pp. 231-243, 1886.

the author has in hand one of these later intrusives or one of the original greenstones, for the field evidence is frequently defective.

Common megascopic characters.

They both show a banded structure which constitutes an apparent stratification. Pp. 97, 125, 164; pp. 133, 154, 185.

They show the same direction of strike and of schistosity. Pp. 110, 129; p. 154.

In both the coarser bands grade imperceptibly into the finer. P. 75; p. 176.

They both have a parallel structure in all their parts, both macroscopic and microscopic, which runs uniformly in the same direction, on a broad scale, for any certain place, but occasionally bands of schistose finer material are seen in each to diverge somewhat from the normal direction. Pp. 129, 132, 203; pp. 156, 186 (Irving).

They both graduate into silvery hydrous schists. P. 105; pp. 177, 190.

They both appear in the form of massive aphanitic greenstones. P. 164; p. 176.

They both appear as massive granular greenstones. Pp. 77, 84, 126; p. 155.

In both the alternation of lighter and darker bands is due to the preponderance of calcite and chlorite, and sometimes of quartz and epidote, in the lighter bands. P. 75; p. 156.

In both the structure of the rock may be irregularly granular, none of the components being in any degree idiomorphic, with frequent and abrupt changes in the coarseness of the grain. Pp. 68, 71; pp. 176, 187.

In both there is an absence of amygdaloidal structure. The only amygdaloidal rock mentioned is 11746, occurring near Baldwin's kilns, in a "well marked dike." P. 174; p. 201.

They both show the peculiar "spheroidal parting." P. 168; p. 177.

They are sometimes entirely destitute of characters that point to an eruptive origin. Pp. 74, 156, 164; pp. 154, 158.

They sometimes manifest clearly certain proofs or signs of sedimentary origin. P. 133; pp. 176, 188.

In the field they cannot be separated geographically.

It may be questioned reasonably whether the rocks of such marked characters, showing such macroscopic resemblances and such close relations, stratigraphic as well as

geographic, can be said to have separate origins. Certainly on the basis of magascopic characters, even when reported by a geologist who entered the field with an avowed leaning (p. 31) toward the eruptive hypothesis, and even reaches a contrary general result, the evidence of sedimentary, or at least a fragmental, origin greatly preponderates.

This bulletin was written under the guidance of the view of Prof. Irving that the iron ores at Marquette and at Menominee are all in one and the same formation, and that none of the ore at those places is embraced within the greenstones. Since then it has been admitted by the geologists of the U. S. Geol. survey that the distinctions made out in Minnesota are observable in Michigan, and hence one ore horizon is much lower than the other, and is, indeed, involved, as in Minnesota, with these greenstones. This misconception of the geologic relations of the Michigan ore bodies is responsible for some of the errors into which the author has fallen. For instance, he has supposed the Eureka iron ore near Marquette to belong to the later "iron-bearing" strata of the region of Negaunee, and excludes it from the greenstones, while actually it is a lens of jasper and impure hematite within the greenstones, shading into novaculytes, east and west, in a manner similar to hundreds that occur in Minnesota. Again, the fragmental chloritic slates which occur below the Four-Foot falls in the Menominee area are excluded from the greenstones on the hypothesis that they belong to the iron-bearing detrital rocks, although there is no structural evidence to show it, but rather everything indicates that they are a phase of the green schists that prevail in the region. The Wisconsin survey sheets xxviii and xxix indicate that these chlorite slates are in the same formation as the greenstones. Again, the greenstone knobs about Negaunee, which certainly are outliers of the main greenstone belt, rising in the midst of the later iron-bearing rocks which lie non-conformably upon their slopes, are thought by Dr. Williams to be of the nature of the later intrusives and comparable to the diabase dikes which cut Lighthouse point. The correction of these misconceptions obviously involves important changes in the conclusions reached by the author as to the derivation and geologic history of some of the rock masses he has discussed.

(b). MICROSCOPICAL FACTS.

In this examination of the microscopical facts reported by Dr. Williams we shall simply collate them as he has determined them, without calling in question their actuality. In case we find reason to ascribe to them different significance, and hence to give them different interpretation, we shall do it with great deference to the learning and skill of the author. The writer has elsewhere insisted on the subordination of microscopic evidence to field evidence, and on the necessity of finding some middle ground on which the opposite testimony of these two methods of research whenever they seem to be contradictory, can find free and consistent standing,* since one natural truth when correctly understood cannot clash with another.

One of the most important and remarkable of the microscopical facts reported by the author relates to the feldspars. Notwithstanding the advanced state of decay which the old greenstones uniformly exhibit, the feldspars are found, even in the most schistose and "crushed" parts of the rock, to be remarkably fresh. In numerous instances the author suggests that they look like fresh crystallizations; indeed, as has already been stated, he deduces a rule that the *freshest feldspars are found in the most crushed rock.* At the same time he finds in the same rock, or the same kind of rock taken at other places, that the feldspar grains have suffered remarkable distortion and destruction under the action of the same mysterious dynamic forces. Although he suggests in several instances that the former may be "new crystallizations," and even concludes that the albite feldspar of the saussurite masses is a new crystallization (p. 158), it appears that he does not adopt what seems to be the most reasonable explanation of this anomalous action of the feldspars of these rocks. He passes the fact as unexplainable, except on the hypothesis that the feldspars may have been able "by slipping" to adjust themselves to the pressure and thus to avoid crushing. Why the quartzes, which appear beside the feldspars, could not have slipped, and escaped the effects of the pressure equally as well as the feldspars he does not explain. They, on the contrary, have been distorted, and sometimes show a peripheral granulation. Why other feldspars, in some such cases, should have been crushed more than the quartzes, is another anomaly which is left unexplained.

---

*Twentieth Report of the Minnesota Survey, pp. 18-22.

These curious freaks of the mysterious agent appealed to by the author (dynamic metamorphism) to account for the present condition of the minerals of these rocks on the hypothesis of their having been massive eruptive rocks, may be, perhaps, understood better if the hypothesis be abandoned, and they be examined from the same standpoint as that from which the banded greenstones of the Marquette area are studied, viz., that of fragmental basic tuff. In such an oceanic terrane there would be of course, primarily, all the elements of a diabase, including feldspars, fragmental and entire. These would graduate secondly, into true erosion sediments, at distant points, or under favorable conditions at near points, but would accumulate rapidly and be consolidated in great masses at those points favorably situated for their preservation. In all cases they would be likely to show the effect of oceanic levigation, and all their minerals would take on more or less of the effects of atmospheric degradation, such changes being effected mainly prior to consolidation. Subsequently, on the application of pressure and shearing, accompanied by heat and by the tilting which has brought all the Archean rocks to a a position of verticality, the original feldspars were crushed and stretched, and many new crystallizations were promoted. This changed the semi-decayed minerals of the original oceanic tuff into reconstructed forms. The feldspars were surrounded, under new environments, by fresh rims or enlargements, or entirely new crystals were generated, the hornblendes extended their limits, the chlorites and micas were strengthened in their chemical integrity and perhaps converted to biotite, and the leucoxene rim of the menaccanite gave off sphene and rutile needles. These reconstructional changes can be legitimately ascribed to dynamic metamorphism, and if so explained and if the decayed appearances exhibited be considered as the effects of oceanic weathering in Archean time, the argument of the author, or so much of it as would remain, would be relieved of all these anomalies. The feldspars which are crushed and faded so as to "lose their outlines in the surrounding matrix" are probably the products of the old volcanic outbursts, original parts of the basic tuffs. Those which are fresh, or have fresh rims surrounding a decayed interior, may be of later date, as shown by Van Hise for certain feldspars of the Keweenawan sandstones.* At any rate in the absence of a demonstration for either hy-

*Enlargements of feldspar fragments in certain Keweenawan sandstones. Bulletin No. 8, U. S. Geol. Sur., 1884, p. 44.

pothesis this would obviate some difficulties, and is more reasonable than to ascribe all these contrary changes to a single force. It would, moreover, allow the megascopic characters to maintain their legitimate significance, paramount to the microscopic, and there would be no conflict in their interpretation. The coarser tuffs, less reduced by levigation, would thus be given the semi-crystalline resemblance to original diabase which the author describes; for they doubtless took on, like some limestones of Paleozoic age, a crystalline texture which obliterates, through great thicknesses, their original sedimentary features.

As with the megascopic characters the microscopic features afford suggestions of massive structures, but the evidence is seldom or never clear and convincing. The evidence of fragmental origin, on the other hand, while in some cases defective, is sometimes undeniable and is acknowledged by Dr. Williams, even for specimens taken from the very midst of rock which he concludes from other specimens to have been a massive eruptive (p. 133). How a massive basic rock, which must have cooled at considerable depth below the surface, can be said to show in places immediately adjacent, evidence of fragmental origin, is one of the difficulties of the argument which Dr. Williams does not attempt to explain, except by the statement that the fragmental rock must be considered to be of the nature of diabase tuff—which is no explanation at all, since it requires a deep-seated rock to be cotemporaneously in contact with an effusive eruptive one. If it be presumed that the diabase was also a surface eruptive rock, it may be answered that it should show some evidence of it, such as amygdaloidal structure or a layering characteristic of surface flows. Such features, however, have not been reported, although it cannot be questioned that occasional liquid eruptions must have occurred as accompaniments of the ejection of volcanic ash. What effect may have been produced on them by contact with the abounding oceanic waters of the time, is not certain, nor apropos at this point. The consolidation of tuffs may be so perfect as to render the resultant rock indistinguishable from an originally massive rock.

It will be well to summarize as follows the statements of the bulletin bearing on the microscopic characters which are the same in the admittedly fragmental rocks and in those which the author supposes to have been originally massive but are now "schistose." This covers the crucial point of the argu-

ment, for, if the "schistose" rocks interbedded with the massive layers, can be shown to be either fragmental or modified massive formations, the coarser ones, whatever the testimony of the microscope, must be of the same origin. We collate, therefore, as with the magascopic characters, those microscopic features which the author ascribes to both, with page references to the bulletin.

Common microscopic characters.

The chemical and microscopic characters of these schists (the banded schists at Marquette) agree closely with those of the associated massive greenstones. Pp. 154, 158.

Mineralogically they are now identical. P. 158.

They both show occasionally lath-shaped feldspar crystals like those of the diabase feldspars. Pp. 98, 163; p. 155.

They both show the development of albite feldspars, both porphyritically and in a saussurite, quartz-albite mosaic. Pp. 68, 78, 209; pp. 155, 157, *et passim.*

Both show the "peculiar" action of feldspar, in that the freshest feldspar is found in the most pressed and stretched rock. Pp. 93, 103, 157; pp. 177, 187.

They both, when "schistose," have a matrix of quartz, chlorite and calcite, with leucoxene and feldspars. Pp. 131, 132; pp. 155, 176.

They both contain striated, often lath-shaped feldspars, round which chlorite scales are seen to shape themselves in sinuous adjustment to the forms of the feldspar. P. 75; p. 176.

In both the feldspars are sometimes so altered that they seem to grade imperceptibly into the matrix (original feldspars). Pp. 73, 74, 81, 98; pp. 177, 187.

In both the feldspars are sometimes fresher than the quartz, and suggest new crystallizations (secondary feldspars). Pp. 78, 88, 112; pp. 156, 187.

They both contain crystals of tonrmaline. P. 200; p. 124.

[*Note.* The only observed instances of tourmaline being noted by Dr. Williams in what he considers a modified basic eruptive rock are on pages 132 and 200. In the latter it is referred to rock No. 11064, which he styles hornfels. There is no description of this rock. It is not mentioned where the author describes the associated numbers, on pages 104 and 105. Nos. 11062 and 11063 are likewise omitted. It is evident, however, from the context that these omitted numbers were collected

in the same place and from the same rock, in general, as Nos. 11061 and 11065, both of which are fully described and considered examples of sheared gabbro. The other instance is mentioned on page 132 (No. 11139) when a chlorite slate, said to be one of the "most altered" rocks of the Lower Twin falls, contains abundant sharply defined crystals of tourmaline].

They both show, in general terms, a degradational change rather than a reconstructional one; that is, they show one that is attributable to the entrance of atmospheric agents. Pp. 81, 91, 93; pp. 156, 184, 187.

In both, the essential composition is fibrous green hornblende, quartz, epidote, zoisite and chlorite. P. 154.

In both the hornblendes sometimes show tuffted ends, suggesting, according to Van Hise, new growths, or, according to the author, a fraying out by some mechanical force which has broken and separated the lamellæ. P. 107; p. 155.

Both contain quartz, both primary and secondary. Pp. 81, 210; p. 155.

Both consist essentially of the decayed and battered minerals of diabase. P. 68; p. 155

There is certainly nothing in the microscopic evidence that indicates different origins for these rocks. That is admitted by the author. It is apparent, therefore, that the author relied on megascopic features, which, as has been shown, preponderates in favor of fragmental origin. If that origin be allowed for the "schistose" belts, which we prefer to call sedimentary beds of finer materials, it will involve all the coarser beds which are plainly interbedded with the schistose, and will leave for the undoubted eruptive portions of the greenstones but a very small moiety; these perhaps may yet be detected and fully distinguished.

The author sums up his views respecting the aphanitic greenstones of the southern Marquette area as follows, on p. 165:

> The history of the schistose greenstones must be deciphered with the conjoint evidence afforded by the microscope, and a study of their relations in the field. The occasional survival of the characteristic diabase structure, even in some of the more foliated forms, taken in connection with their evident identity with and gradual transition into the massive varieties, appears to be sufficient proof that, with the exception of certain unimportant tuff deposits, these green schists have been derived from basic eruptives through the agency of the intense mechanical and chemical action.

This might be paraphrased as follows, and still would not be in contravention of the evidence:

The history of these massive varieties of greenstone, especially the aphanitic ones, must be deciphered with the conjoint evidence afforded by the microscope and a study of their relations in the field. The occasional survival of unmistakable tuff-structure, and of "slaty bands traversing the massive greenstones," even though exhibiting unimportant acquired resemblances to an original diabase-structure, taken in connection with their evident identity with and gradual transition into less foliated forms, appears to be sufficient proof that, with the exception of certain unimportant and undoubted eruptive masses, some of which may have been of later date than the main body of schists, these greenstones have been derived from basic tuff deposits through the agency of intense pressure which developed sometimes a mechancal and, more rarely, a chemical effect.

GENERAL CONSIDERATIONS.

(a) *Dynamic metamorphism as a theory.*

The eruptive basic rocks, or their tuffs, with which this bulletin has to do, were produced in their original condition, by *dry fusion*, in the natural laboratories of the earth. Some of them have been reproduced artificially by Messrs. Fouqué and Michel-Lévy.* They must therefore have exhibited at first the most ultra crystalline condition which such elements can be supposed to be susceptible of. Any change which they might suffer could only be brought about by the action of some force which would loosen the high chemical tension in which their atoms may have been placed by the process of cooling from dry fusion. Such change could only be brought about by the access of atmospheric elements, consequent on some of the natural vicissitudes of eruption. At once on the access of atmospheric agents, or on the subjection of these mineral compounds to other physical surroundings, a degradational change must have been started. No other change would be possible. Whether this change began immediately after ejection as volcanic matter, or before ejection, but after the magma came within reach of surface influences, such as aqueous vapor or lessened pressure, it was still a descending process, one which, when continued and completed, would finally reduce the minerals to an oxidized powder fit for mingling with the ordinary sediments of erosion. This, however, cannot be called *metamorphism*, as that term is defined and used. It is essentially a weathering process, although "weathering" is not usually supposed to begin before the rock is solidified and exposed to the ordinary action of the atmosphere. All upheaval, all crushing, or shear-

*Synthèse des minéraux et des roches. Paris, 1879.

ing or simple pressure, in so far as they facilitate the approach of atmospheric agents to the rocks affected, serve as means of degradational change. In so far as they produce heat which is brought to bear upon the crushed minerals, especially if it be conveyed to them by the action of aqueous vapor, there is a tendency to reconstruction and a restoration of the former crystalline integrity. Since, therefore, it is a fundamental law of physics that all force which is expended in such great movements as upheaval, and such friction as crushing or shearing or folding, produce equivalents in heat, it is necessary to allow for the presence of large amounts of heat when these dynamical processes were carried out. Since, further, water in the form of aqueous vapor has been present in all volcanic ejections, and, as water, has permeated all the rocks of the earth's crust, it is equally necessary to admit the presence of both heat and moisture at all places where any dynamic changes such as those mentioned have taken place, throughout geological history. Such movements, therefore, in their ultimate results, when acting normally at any depths within the earth's crust would leave the concerned original massive strata with a lower stage of crystallization than they had prior to their action. They would tend to solidify and reconstruct the fragmental grains of sedimentary strata, and would reinforce the igneous rocks in case they had begun to suffer from atmospheric agents. At still greater depths, beyond the reach of air and water, such pressure may have been sufficient to re-fuse the crust, allowing the product to return to its native condition. Near the surface of the earth, only, and in exceptional cases, could the heat which such changes must have created be supposed to have been dissipated without causing the recrystallization here indicated.

Metamorphism, therefore, in the sense in which the word is commonly used, is not a degradational change. It is the "passage, under circumstances of high temperature or pressure, or both, of less crystalline into more crystalline compounds; or the change of minerals into others not less crystalline or insoluble than themselves" (p. 36). Such changes are promoted in all fragmental rocks by the great dynamical movements to which the author has appealed. The retrogressive changes described by the author are not metamorphism, properly so called, they are instead *katamorphism*.

We do not desire to question the possibility, nor even the actuality of the mineral changes which are included under the

term "dynamic metamorphism" by the author. Given a basic crystalline rock, and a fragmental one of the same chemical composition, like the tuffs at Marquette, and let them be subjected to equal pressure and shearing, with access of heat and moisture, and they would be made similar in mineral composition and perhaps in some of their structures, in the former by katamorphism and in the latter by ordinary metamorphism. They would both be changed to a crystalline schist, acid or basic according to the nature of the original rock. Such changes have passed over the rocks in vast areas of the earth's surface. Such changes are apparent in the basic tuffs wherever they are found to approach the region of the eruptive granites, whether in Michigan or in Minnesota. Toward the "eruptive" greenstones they show no such change, although they approximate the greenstones in all their characters. This fact indicates that the tuffs have not been subjected to any metamorphism worthy to enter into this discussion, and inferentially that the greenstones have also been exempt. The supposed dynamic changes described by the author in what he considers original diabases are precisely the same as those which he finds in the stratified tuffs. But, as already stated, we consider that a dynamic force which would have wrought such destructive changes in a diabase would have recrystallized the tuff which was associated with it. If they show the same characters now, as admitted by the author, they must have had a similar physical history since their deposition, and, as the tuffs are in an extremely decayed condition, the supposed diabase must have begun its history with a similarly decayed condition—in other words, it would not have been an original massive eruptive.

We are, therefore correct in assuming that the profound and ever-present retrogression in mineral crystallization which the greenstones exhibit cannot be attributed to dynamical movements, except in limited and irregular areas which cannot yet be defined, and that in general it must be referred to some cause whose natural effect looks toward the opposite direction, and which acted alike and simultaneously on the material of the greenstones and that of the fragmental tuffs.

We can find no cause adequate to the production of these changes except atmospheric action on volcanic ejectamenta. In case of lava flows contemporary with the tuff accumulation, such may have been largely or wholly destroyed by the solvent action of the ocean, or so permeated by the same changes that

when consolidated they lost their identifiable features as igneous rocks. The saussuritization of feldspar with separate formation of zoizite and secondary silica is described by Prof. J. W. Judd* as the product of ordinary weathering of the gabbros of Mull, west coast of Scotland. "Every stage of this alteration (a kind of kaolinization) can be traced, from a slight clouding of the transparent feldspars to their passage into white and opaque pseudomorphs. Colorless augites acquire a brown or purplish tint on their exterior portions, which extends inward and finally embraces the whole crystal. They also change paramorphically to hornblende and to diallage, and in other cases to the structureless viridite which again becomes hornblende by uralitization. Enstatite and olivine produce serpentine, and ilmanite leucoxene. The whole rock may be still further decayed by atmospheric exposure "and reduced to a mass of dark colored clay, or wacke." He also remarks that this action results in a destructive change in the rock, whereas crushing movements in rock masses result in reconstructive changes. At any rate, so long as it cannot be affirmed that it is proven that dynamic movements were the only possible cause of these features, it is reasonable to allow that they may be referred to some other agent. The thesis of this bulletin would be proved had the author established the two following propositions. (1) Dynamic forces can produce the effects seen in the decayed conditton of the minerals of all the greenstones and the fragmental schists. (2). Dynamic action is the sole efficient cause that can have produced these effects. Lacking both of these, as it appears to the writer, the philosophy of the author is not sufficiently intact to warrant its unqualified acceptance.

(b) *The greenstones as a geologic terrane.*

It has already been shown that the greenstones of the Archean constitute a district terrane, forming the latest portion of the Keewatin, thus coming at the very top of those rocks which, in the lake Superior region, have been found to constitute the "fundamental complex." The Archean terminates abruptly, by the most profound plane of non-conformity that has yet been discovered in American geology. Its bedding, i. e., its sedimentary structure, stands vertical, or nearly so, at all places where it has been examined and reported. The basal beds of the Taconic pass transversely over them, indicat-

*Quart. Jour. Geol. Soc. xlii, p. 84. 1884.

ing a general subsidence beneath the ocean on the close of the volcanic age. Below the greenstones are found chlorite slates and schists, sericitic schists, clay slates, graywackes, conglomerates, quartzytes and jaspilytes. The greenstones pass gradually, by various alternations of "massive" and "schistose" greenstones, into chlorite slates, and then into clay slates. In other places these green schists verge off with an increase of very fine silica grains, into silky schists and to novaculytes, and with local increase of hematite into jaspilytes. These schists may all become so coarsely fragmental as to constitute conglomerates, "slate conglomerates," graywackes, siliceous porodytes and conglomerates made up of porphyritic felsyte pebbles. Whatever their composition, we have about come to the belief that they are all the result of oceanic action on volcanic ejectamenta. Their thickness in Minnesota seems to exceed that of any other of the Archean terranes. The Vermilion iron range is in this formation. We have discovered no general plane of discordance in the midst of this volcanic material. The conglomerates are local and irregular, and vary, not in accordance with the strata alongside of which they lie, as they would if they were of erosion origin, but wholly independently and irregularly. Generally, indeed, their pebbles cannot be referred to any rock in the region. They are like the pebbles described by Dr. Williams in the Deer lake agglomerate, quartz-porphyries and felsytes, ambiguous greenstones and red granites, with occasional angular pieces of jaspilyte. They seem to have all been thrown out from volcanic craters, and to have been spread out in comformable sheets by oceanic action, sometimes after long continued abrasion.

This series of fragmental materials has been locally and regionally affected by metamorphism, and has been converted into true crystalline schists. Restricted gneissic and granitic areas are surrounded by such schists, and the gradual transition from the fragmental Keewatin into the crystalline schists has been observed at many places. There is no general plane of non-conformity between them. In tracing the Keewatin schists downward, or at least in a direction toward the great areas of gneiss and eruptive granite which is often presumed to be in descending order, there is a gradual increase of crystallization until the rock is a fully crystalline mica, or hornblende-mica schist, which, in turn, becomes an acid gneiss by the continued increase of quartz and orthoclase. In general it may be

said that throughout the series, from the top of the Kawishiwin to the gneiss of the Laurentian, there is no widespread plane of non-conformity, but a succession whose most marked characteristic is a gradual change, in descending order, from basic fragmental tuff-rock, with some which may have been originally massive, to acid schists and gneisses, the latter being wholly crystalline and fresh. This change in the schists is attributed to "regional metamorphism," but how it differs from local or contact, or even from dynamic metamorphism, it is not possible to discover, except that it is carried out on a much larger scale. The sedimentary structure is everywhere apparent and unquestionable. In the gneisses are sedimentary structures as apparent as in the schists; and at the same time the gneisses or, perhaps more properly, some granites which have acquired a foliated or sheeted structure, exhibit other "parallel structures" which have sometimes been mistaken for the sedimentary structure.

From this review it becomes apparent that the volcanic age was one whose action began feebly, its tuff constituting but a small part of the oceanic deposition. It increased throughout a vast lapse of time and culminated with a volcanic violence which seems to have everywhere terminated the Archean, and was followed by such a settling of the land areas that the following, or Taconic age, was introduced by a very general submergence, bringing the base of the Taconic nonconformably over the upturned beds of the Archean. It also becomes apparent from this review that the decayed greenstones and greenstone tuffs are much younger than the truly crystalline schists. They could not therefore have been metamorphosed nor subjected to any general dynamic force, such as pressure, folding and shearing, unless the same movements had involved the lower terranes. If the philosophy of dynamic metamorphism be correctly applied by the author it will be necessary that it shall answer the question—why do not the crystalline schists exhibit the same or similar semi-decayed crystallization as the greenstones and basic tuffs? and the question, why have not the eruptives (?) of the greenstones preserved their structures as intact as those of the older crystalline schists?

We look upon the greenstones in Minnesota as an oceanic terrane having a definite stratigraphic position, although probably involving some truly irruptive masses. Its materials, both basic and acid, are interbedded by sedimentation the one with

the other, and are sometimes mingled. The decayed condition of these materials is due to the natural action of the Keewatin ocean prior to consolidation, and the crystalline condition of the lower beds is due to a later metamorphism which, having its active forces and seat at still greater depths, did not permeate the whole formation. It is not attributable so much to dynamic movements as to internal heat. Wherever such movements operated with great violence, the lower Keewatin sediments were fused, producing irruptive felsytes and granite. Such granite is bordered usually by belts of crystalline schist, evidently formed at the time of such fusion.

III.

PRELIMINARY REPORT ON THE RAINY LAKE* GOLD REGION.

By H. V. Winchell and U. S. Grant.

CONTENTS.

*There is an idea more or less prevalent, and it has been stated in print, that the name of this lake is derived from a corruption of the French names Regnault or René, neither of which has the same meaning as the English *rainy*. There are no good grounds for this idea, which appears to be merely an assumption. The earliest map we have seen, on which this lake is represented, is that by Ochagach, an Assiniboine chief, who traced it for Verendrye in 1730. On this map Rainy lake is called "*Lac Tecamamisuen*." The next map on which Rainy lake is shown is that of Buache, entitled "Carte physique des terrains les plus élevés de le partie occidentale du Can-

INTRODUCTORY.

This report makes no pretension to be an exhaustive description of the Rainy Lake country and of the gold interests centered there. The time allowed for study in the field and in the laboratory has been entirely insufficient for the preparation of anything but a preliminary paper. The authors have, however, endeavored to present a report which will give some precise and reliable information concerning this region, the occurrence, richness and necessary treatment of the ores, the geological structure, and the other resources. It is hoped that this report will be of value as an easily accessible source of information to intelligent persons who desire to gain some knowledge of this district, as well as to those who are now in the region or who are contemplating visiting it.

The description of the geology and the general physical features of the Rainy Lake region applies especially to that part of the lake and its shores lying in Minnesota, but most of the statements will hold equally well for the territory on the other side of the International boundary. When certain features find better development in Canadian territory this fact will be mentioned. The geological observations of the authors have been supplementary to, and in a large degree confirmatory of, the reports on this region written by A. C. Lawson* and H. V. Winchell.† To these reports we are indebted for corroboration of many of the facts observed in the field, and in some cases for statements which are essential to this report, but which we are unable to make wholly on our own authority. This general acknowledgment will suffice to make it unnecessary to give references in cases where our observations agree with those of the above mentioned authors, but where we are entirely indebted for certain statements to the previously published reports reference will be made to the source of the information.

ada" and published in 1754. On this map Rainy lake is designated as "*Lac Tecamamiouen ou de la Pluie*," which is sufficient proof that at that early date, one hundred and forty years ago, the lake was known to the French explorers as *Lac de la Pluie* (Lake of the Rain). There are thus most excellent grounds for the belief that the name Rainy lake is a direct translation of the original French designation. Most likely also the French name was a translation of the Chippewa name.

*Report on the geology of the Rainy Lake region. Geol. and Nat. Hist. Survey of Canada, Ann. Rept. for 1887-'88, new series, vol. iii, pp. 1 F-182 F. pls. 12-19, 1889. Accompanied by a geological map.

†Report of observations made during the summer of 1887. Geol. and Nat. Hist. Survey of Minn., 16th (1887) Ann. Rept., pp. 395-478, 1888. Accompanied by a geological map.

GOLD, ITS OCCURRENCE AND ASSOCIATIONS.

Gold is found in rocks of every geological age. It occurs in the oldest and the most recent, both acid and basic, eruptive and sedimentary. In many districts it occurs in lodes composed of partially metamorphosed rocks, such as slates or schists, while its occurrence in holocrystalline metamorphic or igneous rocks is comparatively rare. Among sedimentary rocks its occurrence is almost confined to the sands of rivers which run for a part of their course through crystalline formations, or more particularly through districts in which gold occurs in quartz veins. Such river sands are rarely quite free from gold. The beds of ancient rivers no longer existent are also frequently auriferous.* The matrix in which the gold is contained is usually quartz, intersecting as veins or interlaminated with, subcrystalline, slaty or schistose rocks, especially hydromica and chloritic slates. Gold also occurs sparingly in similar veins in granite and gneiss, and has been detected in the trachytes of Colorado, and in Silurian and Carboniferous trachytes, as well as in some limestones.

The wide distribution of gold in minute quantities throughout the world was pointed out by W. E. Dubois in 1891** and is thus commented upon by W. P. Blake: † "There is a much greater dissemination of gold in a ragged granular condition, *in situ*, in fine particles in the midst of rock formations, and without any obvious connection with veins, than is generally supposed. Prominent examples are found in the belts or zones of layers of soft slate in Georgia, and in North Carolina. * * * * The Boly-Fields gold vein, Lumpkin county, Georgia, is an example of the occurrence of coarse, ragged gold in the midst of a mass of slate, without any defined quartz vein. The gold is closely associated with bornite, pyrites and dolomite." The dissemination of gold in the schistose rocks of North Carolina has also been noted by professor Kerr,†† and by Dr. Emmons, and similar occurrences have been noted in Texas, Nova Scotia, and in other parts of the world. At the Contention mine, Tombstone, Arizona, free metallic gold is found in the thin cracks and cleavage surfaces of partially decayed porphyry, and appears to have been deposited there from solution and not mechanically. It occurs in thin subcrystalline

*Rose. Metallurgy of Gold, 1894, p. 33.

***Jour. Am. Phil. Soc.*, June, 1861.

†Prod. Gold and Silver in the United States, 1884, p. 581.

††*A. I. M. E.*, X, 475.

flakes and scales, and may have been derived from the decomposition of the iron pyrites with which the adjoining sedimentary formations are charged. Gold also occurs in small quantities (1 part in 1,124,000) in the bed of clay on which the city of Philadelphia is built.*

According to Rose the most common mineral associates of auriferous quartz lodes or placer deposits are platinum, silver, iridosmine, magnetite, iron pyrites, galena, ilmenite or titaniferous iron ore, copper pyrites, zinc blende, tetradymite, zircon, garnets, rutile and heavy spar; wolfram, scheelite, brookite and diamonds being less common. Diamonds are associated with gold in Brazil, and also occasionally in the Urals and in this country. The sulphides present in auriferous quartz frequently contain gold, which is usually in part quite free, disseminated through the quartz, in visible grains, and in part locked up in the pyrites, whence but little can in general be extracted by mercury. It is, however, in all probability in the metallic state in pyrites, as was shown by F. D. Adams to be the case in ore from the Alaska Treadwell mine.† Calaverite is a telluride of gold, while sylvanite or "graphic tellurium," petzite and nagyagite are tellurides of gold and silver. Other gold tellurides and some native gold amalgams are occasionally seen, but none of these minerals are of much importance as ores, seldom occurring in any abundance. In Colorado, however, are a few mines in which the valuable ores are tellurides.

Placer gold is usually in the form of small scales, but pellets or rounded grains also occur, while larger masses or nuggets are usually of a rounded, mammillated form. The chief difference between the appearance of placer and vein gold lies in the fact that the former is always rounded, showing no sharp edges, even the crystals having their angles smoothed and rounded off. This has been pointed to by the advocates of the erosion theory of the origin of placer gold, as evidence in favor of their views, the roundness of the fragments being taken to prove that abrasion of the gold has been effected by attrition through moving water and grains of sand. The largest masses of gold yet discovered have been found in auriferous gravel,‡ but recent reports from the Coolgardie district, in western Australia, indicate that larger masses of gold may yet be found in quartz veins than have ever yet been taken from

*Rose, *loc. cit.*, p. 30.
†Am. Geol., IV, p. 92.
‡Rose. *loc. cit.*, p. 31.

placers. This will deprive the supporters of the chemica. theory of the origin of gold in placers of one of their most effective arguments.

Native gold usually contains silver in varying proportions, its color becoming paler with the increase of silver. Copper almost invariably contains gold, and even the Lake Superior copper, celebrated the world over for its purity, contains nearly one part of gold in a million of copper, The bronze and copper coins of all nations are usually found to contain greater quantities of gold than this. Similar evidence has been adduced, tending to show that all ores of silver, antimony and bismuth contain gold.*

Even the waters of the ocean contain gold, as demonstrated by Sonstadt in 1872.† Münster, in 1892, found an average of five milligrams of gold in a ton of sea water, or 26 tons of gold in a cubic mile of water. It has been estimated that the ocean has an average depth of 2,500 fathoms and contains 400 million cubic miles of water, thus holding in solution 10,250 millions of tons of gold, To appreciate to a slight extent the significance of this statement we have only to consider that the world's total output of gold during the past 400 years has been only about 5,300 tons and now amounts to about 200 tons per annum. If our gold were all taken from the ocean the "visible" supply would be sufficient to last 51 million years at the present rate of production.

The gold thus contained in the sea is held in solution as an iodide. But the gold which occurs in the rocks of the earth's crust is almost entirely native. For many years it was supposed that gold was not taken into solution by any but the most powerful reagents to form chemical compounds. It is now known, however, that gold is soluble in several of the most common acids and salts, and is transferred by them from place to place and redeposited.

I. VEINS AND THEIR ORIGIN.

It is quite probable that the original source of gold was in disseminated form in eruptive rocks. From these it has been segregated either directly into veins which cut these eruptives or into veins contained in sedimentary rocks which were formed from the decay and redeposition of the original eruptives. The minerals usually associated with gold in veins are quartz and pyrites. Other minerals such as galena, zinc blende, and other

*E. A. Smith, on Bismuth, etc., *Jour. Soc. Chem. Ind.*, XII, 1893, No. 4.
†Chem. News, XXVI, p. 159.

sulphides or carbonates are not uncommon, but quartz and pyrites are the companions of gold the world over. Upon the decay and erosion of the pyrites and quartz the gold is usually found in flakes or nuggets of greater purity and size than before the pyrites is oxidized. The portion of a gold bearing vein which has been thus affected by oxygen-bearing waters sometimes extends to the depth of two or three hundred feet and is frequently richer than the ore found at greater depths. When decay and erosion have progressed still further and the veins are broken down and washed away, the gold is found in the resulting gravel deposits, called placers, in the beds of streams and gullies. Such placers have produced a very large proportion (about two-thirds) of the world's store of gold, and at the present time placer gold amounts to about 40 per cent. of the total output.

Veins are differently defined by different writers. Phillips says they are "aggregations of mineral matter, differing in character from the enclosing rocks, in fissures formed in those rocks subsequently to their consolidation."* He says further that "true veins" traverse the enclosing rocks independently of their structure and not parallel to their foliation or stratification. Veins of this class are believed to have originated in fissures or faults produced by movements of portions of the earth's crust and to extend to an indefinite depth. It was formerly believed that unless a vein was of the variety called a "true" or fissure vein it had little value. This is not true, however, many large and profitable workings being in segregated or "bedded veins" which are in a general way parallel with the enclosing rocks, or even in mere impregnations of the rocks themselves.

It was at one time a common belief that veins and their contents were formed at the same time as the rocks which contain them. Then it was seen that they must be later than the rocks and of different relative ages, and it was popularly supposed that they were fissures filled by material which was forced into them in a molten and fluid condition from great depths. It is now generally thought that the contents of veins were deposited gradually from the various solutions which are continuously circulating through the rocks below the surface. Chemical analyses have revealed the presence in these solutions or ground waters of the various minerals that are now being deposited on the walls of the fissure from which they were

*Ore deposits, p. 50.

taken. The idea of sudden and volcanic or eruptive origin has given way completely to that of slow deposition through the agency of water.

Although silica, or quartz, is insoluble in the ordinary sense of the word, yet it is well known to geologists that it is held in solution in spring, river and sea waters. Thus Forchammer found in some samples three parts of silica in one million parts of water or 13,500 tons of silica in one cubic mile of sea water. Deville showed that the river Loire contained about four parts of silica in 100,000 parts of water. The waters found in mines also contain silica in solution. Daubrée proved experimentally that superheated steam has a solvent action on silicates and that upon lowering the temperature of the solution crystalline quartz of a character similar to that found in association with gold in quartz veins is precipitated. Silicified wood is another example of the fact that silica enters into solution, and is deposited by the reducing agency of organic and other matter. The quartz of auriferous lodes is then accounted for on the hypothesis of aqueous solution and precipitation.

Gold is also usually pronounced soluble only in chlorine, bromine, iodine and one or two other chemicals that are uncommon in nature; and if that were true there would be some difficulty in accounting for its presence in quartz veins formed by deposition from water. As a matter of fact, however, there are many solvents for gold, among them the following: (1) Sesqui-chloride and sesqui-sulphate of iron. Hence J. A. Phillips suggested that in the presence of a reducing agent sulphate of iron carrying gold in solution would be changed to pyrite or sulphide of iron, and the gold reduced to a metallic state. (2) Hyposulphite of soda. (3) Sulphuretted hydrogen at ordinary temperatures, producing a sulphide of gold which is soluble in alkaline sulphides, both of which reagents are generally present in underground waters. (4) As shown by Prof. Egleston, gold is soluble in the following:

Potassium bromide, heated to 150° to 200°C.
Potassium iodide, " 100° to 170°C.
Ammonium nitrate with ammonium chloride as impurity, at ordinary temperature and pressure.
Potassium sulphide at ordinary temperature and pressure.
Sodium " " " " " "
Potassium cyanide " " " " "
Ammonium sulphide heated to 145° to 180°C.
Free chlorine.

"He concludes from his experiment sthat gold is not only not insoluble, but that in nature it is constantly being dissolved out of the rocks and placers, the waters of filtration dissolving out of the rocks, in their passage through them, all the materials necessary for the solution of the gold, and carrying it in very dilute solutions until it meets some substance that precipitates it. * * * * The same conditions which cause the solution of gold in certain cases cause also the solution of silica. * * * No single agent is so powerful a solvent of gold as chlorine. Very few drainage waters are free from some compound of it, and no soil is without the nitrogenous materials necessary to set the chlorine free, and therefore capable of attacking the gold and rendering it soluble."*

Mr. Philip Argall speaks as follows regarding the origin of gold:†

1st. Australian geologists have long held that part of the gold held in the reefs was derived from the ocean, and was deposited with the strata now enclosing the veins.

2d. Gold was also derived from the eruptives, particularly the dioryte (greenstones).

3d. Gold, throughout the world, is of somewhat similar origin, and is in all probability mostly derived from igneous rocks.

4th. Gold readily enters into solution, and is so found in mine waters, and impregnating mine timbers, in association with the alkalies and alkaline earths combined with sulphur.

5th. These mine waters chiefly consist of the alkaline chlorides and sulphates.

6th. That waters holding these salts in solution are found in the inclusions of vein-quartz carrying the precious metals.

Experiments conducted by E. Cumenge tend to show that the alkaline auro-silicate, obtained in the wet way, may have played an important part in the formation of auriferous quartz.‡

HISTORICAL SKETCH OF GOLD DISCOVERIES IN THE LAKE SUPERIOR REGION.

There are reasons for believing that the first discovery of gold in the Lake Superior region was made by Dr. Douglass Houghton in 1845 not far from the present town of Negaunee. The story is told by Mr. S. W. Hill, and a voyageur named An-

*_Trans. A. I. M. E._, ix, 645, 646, 1881.
†_Trans. A. I. M. E._, xxii, 71, 193.
‡Rose, Metallurgy of Gold, London. 1894, p. 27.

toine du Noir. They agree in the statement that Dr. Houghton wandered away from camp one day, alone, as he was accustomed to do, and returned about dark with a bag full of specimens in which native gold was plainly visible. He told them that they were in a gold country, and that he should not be surprised to find quantities of it in the Huron hills. A piece of the quartz found at that time was worn as a pin for many years by Mr. Jacob Houghton, a brother of the doctor. The notes of this season's work were lost in the lake at the time of Dr. Houghton's death, but the accounts of the explorers are generally believed to be trustworthy and the discovery of the Ropes vein in this same vicinity at a later period is very strong corroborative proof of their verity.

Beyond the traces of gold found in assaying the silver and copper ores of Michipicoten island and other localities around lake Superior, there was no gold discovery or "boom" until 1865. In this year gold ore was reported from Vermilion lake, Minnesota, by state geologist Eames and others. A wagon road was laid out from Duluth to the new Eldorado, a distance of 75 miles through the forest. Prof. N. H. Winchell speaks as follows about this Vermilion lake development:* "At that time a flush of feverish excitement led to the expenditure of considerable money in sinking shafts and erecting works for mining. Three steam stamp mills were erected, another running by water power. One was owned by the New York Mining Company, whose location was near the "Mission" on the south shore, another by Nobles and Company, further northwest, and another by Seymour and Company. The water power mill was owned by the Wabasha Company, and was located about two miles from Vermilion lake, at Trout lake. Eight or ten mining companies were at work simultaneously in different parts, mainly on the southern shores, or on islands. A townsite was laid out at the southern extremity of the lake, several large buildings put up, and stated communication made with Duluth. The village was named Winston. Above the village, at Pickerel falls, a lumber mill was projected and the foundations laid." The very land subsequently found so valuable for iron ore, where the hard hematite and jasper stood out in bald knobs, a hundred feet high, was taken for gold claims. The veins, however, proved to contain more pyrite, marcasite and pyrrhotite than gold, and by 1867 the country was deserted, iron deposits and all.

*Seventh Ann. Rep. Minn. Geol. Sur., p. 73, 1878.

The next gold discoveries were in Canada and were made in 1871 by Peter McKellar of Fort William, Ontario. The vein is said to be six or eight feet wide, composed of quartz and intercalated layers of green schist. The country rock is chloritic and dioritic schist, siliceous magnetite and massive dioryte, all having a northwesterly dip of 65° to 80°. The vein strikes and dips nearly conformably with the enclosing rocks. Intrusive syenite appears about a mile to the northeast. The mine developed here was called the "Huronian" and is situated on location "H 1" in Moss township near lake Shebandowan, about 70 miles northwest of Port Arthur. A 10-stamp mill was erected in 1883 and operated for a short time in 1884 and 1885. The gold occurs native and in combination as a telluride, associated with galena, pyrite, chalcopyrite and zinc blende. It is said that the mill "cleaned up" $21.00 per ton of ore stamped, and that much of the gold was lost. Owing to the expense of procuring supplies the mine has not been worked since 1885.

In 1872 gold was found on an island in Partridge lake, a short distance west of Lac-des-Mille-Lacs in a large quartz vein cutting "Huronian" schist. Samples from this vein which showed nuggets of gold were exhibited at Philadelphia in 1876.

In 1875 small nuggets of gold were found in a vein of quartz intersecting reddish granite at Victoria cape on the western side of Jackfish bay, on the north shore of lake Superior. Another vein of quartz 1½ to 3½ feet thick, holding iron pyrites, galena and blende and cutting the granite in close proximity to a slaty dioryte at this locality yielded on assay $27 worth of gold per ton.*

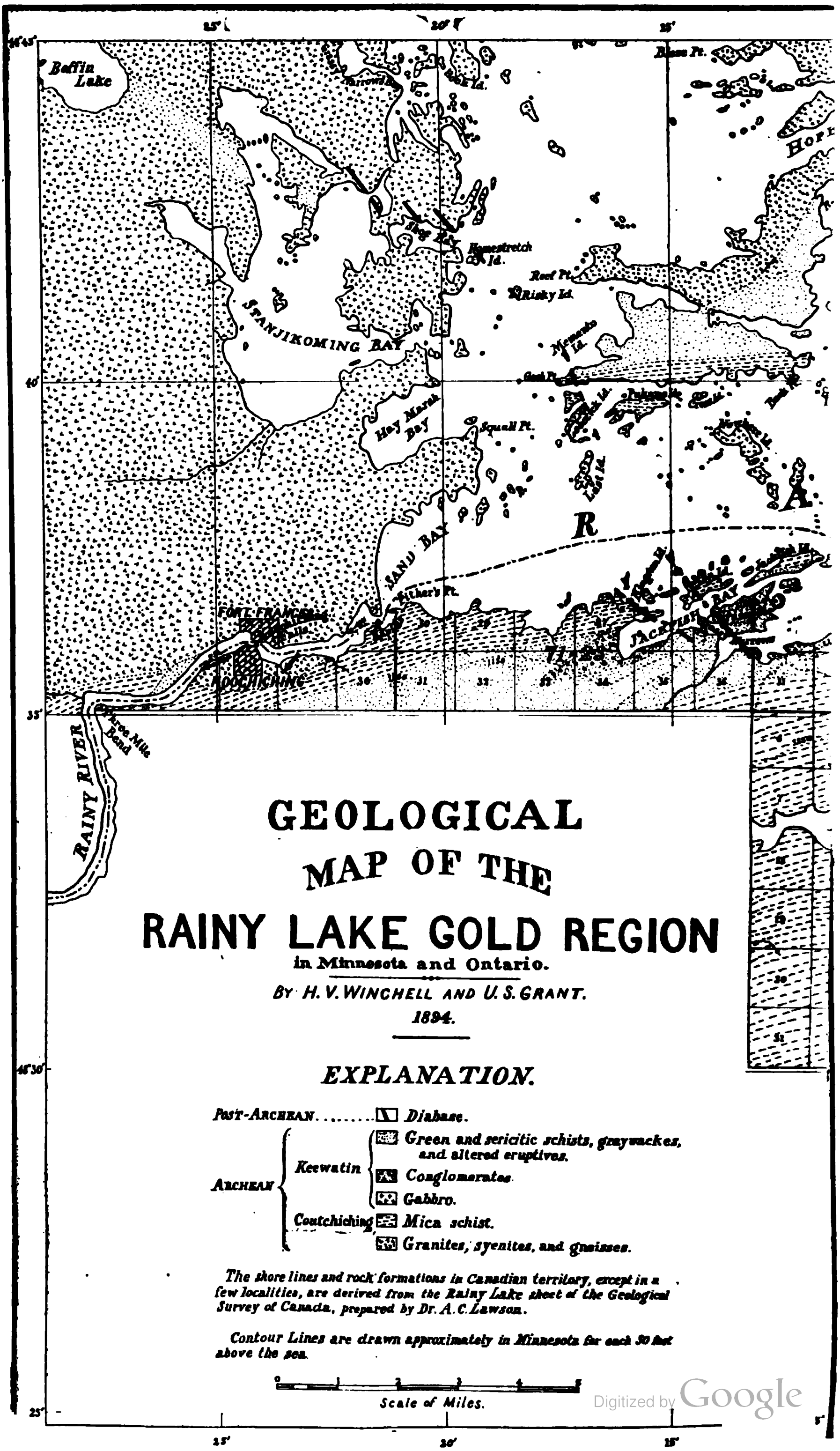
Gold has been known to exist at Lake of the Woods since 1878, and has been referred to in the Canadian geological reports and other literature. The title to lands in that vicinity being claimed by both the Ontario and Dominion governments, mining was not actively prosecuted until 1890 or thereabouts. It is difficult to learn what success has attended mining operations in this district. It is certain that many of them have been unprofitable, but whether this has been due to the poor quality, small quantity, or cost of mining and treating the ore, or to the lack of scientific mining and metallurgical methods could not be ascertained. The rocks of this region are quite similar to those around Rainy lake, and it might be supposed there would be some similarity between the veins of the two districts. If, then, there are profitable mines on Lake of the

*Report Royal Commission of Ontario, Mineral Resources, 1890, p. 26.

Woods, there is encouragement for Rainy lake. The Sultana mine is often referred to as having been operated profitably, notwithstanding the money wasted in apparatus for handling refractory ores of which the mine is said to contain less than five per cent. Indeed, it is doubtless because of the mistaken idea that the gold ore of the Lake of the Woods is refractory that more development work has not been accomplished, and more information gained as to the true character and richness of these veins.

In 1881 Mr. Julius Ropes noticed gold in a vein about six miles northwest of the city of Ishpeming, Michigan. Regular mining was begun here in October, 1882, and during the following summer a 5-stamp mill was erected. In 1884 a 25-stamp mill was completed and put in operation. This is the only genuine gold mine in Michigan, although there have been other discoveries of gold in quartz veins, and considerable prospecting in the shape of test pits and shafts. In 1885 considerable excitement was caused by the discovery of gold three miles west of the Ropes mine on land belonging to the Lake Superior Iron Mining company. Some beautiful samples of ore were obtained here, but the average did not warrant the expenditure necessary to develop a mine, and the project was abandoned.

All of the auriferous quartz lodes of the Lake Superior region are in rocks of Archean age. The majority of them are in the green schists and are not of the class called "true fissure" veins. None of them have thus far been markedly productive, and most of them have failed to yield any profit whatever. If there are any which promise to become paying mines it must be because of cheaper methods of treating the ore or the presence of better ore resulting from more favorable geological conditions in their immediate vicinity. For a description of the geology of the Rainy Lake region as well as the different "prospects" thus far discovered in that district the reader is, referred to the sections of this report entitled "General features and geology," (p. 47) and "Descriptions of veins in general and of individual properties" (p. 72).


GEOLOGICAL
MAP OF THE
RAINY LAKE GOLD REGION
in Minnesota and Ontario.
BY H. V. WINCHELL AND U. S. GRANT.
1894.
EXPLANATION.
POST-ARCHEAN .... Diabase.
ARCHEAN
Keewatin
Green and sericitic schists, graywackes, and altered eruptives.
Conglomerates.
Gabbro.
Coutchiching
Mica schist.
Granites, syenites, and gneisses.
The shore lines and rock formations in Canadian territory, except in a few localities, are derived from the Rainy Lake sheet of the Geological Survey of Canada, prepared by Dr. A. C. Lawson.
Contour Lines are drawn approximately in Minnesota for each 50 feet above the sea.
Scale of Miles.
Baffin Lake
STANJIKOMING BAY
Hay Marsh Bay
Sand Bay
Squall Pt.
Risky Id.
Reef Pt.
Homestretch Id.
Fisher's Pt.
FORT FRANCES
KOOCHICHING
RAINY RIVER
Three Mile Bend
JACKFISH BAY
R
A

GENERAL FEATURES AND GEOLOGY

I. GENERAL FEATURES.

Location.

The area shown on the accompanying geological map (plate I) comprises the region here reported on. Roughly speaking it includes the northeastern corner of Itasca county, the northwestern corner of St. Louis county and a belt of country, eight to fifteen miles wide, immediately to the northward in Ontario. More accurately the region mapped and described extends from the east side of range 18 W., St. Louis county, (about longitude 92° 34′ west of Greenwich), west to the west line of range 24 W., Itasca county (about longitude 93° 29′), a distance of forty two miles; and from the south side of township 69 N., (about latitude 48° 25′) north to latitude 48° 45′, a distance of twenty-three miles. The map thus includes 966 square miles, which are about equally divided between Minnesota and Ontario.

Rainy lake comprises the larger part of the water surface in the area mapped. It extends along the International boundary from Kettle falls, in sec. 30, T. 70 N., range 18 W., westward to its outlet in sec. 25, T. 71-24, a distance of about forty-one miles. Less than one-fourth of the surface of the lake lies in Minnesota, and several bays extend north and northwest of the area shown on the geological map.

Rainy Lake City, which was the first town started in this district in Minnesota, is situated in section 34, T. 71-22, Itasca county, and is 135 miles in a straight line north-northwest of Duluth and 250 miles north of St. Paul and Minneapolis. Koochiching, Itasca county, and Fort Frances, Ontario, are on opposite sides of the Rainy river at Koochiching falls, twelve miles west of Rainy Lake City and two and a half miles west of the outlet of Rainy lake.

Topography.

Rainy lake is a very irregularly outlined body of water with many crooked bays and numerous islands, which vary in size from mere reefs to those several square miles in extent. The surface of the lake, inclusive of islands, has been computed to include 344 square miles. Its extreme length is from the east end of Hale bay, which is about four miles east of Kettle falls. northwestwardly to the extremity of Northwest

bay, in all, fifty-five miles. The extent of the lake east and west is forty-six miles, and the extreme width (north and south) thirty-three miles, of which twenty-three miles are in Canadian territory. On account of the irregular shape of the lake and its numerous points and islands there is no very considerable stretch of open water, but in a few places the view is unobstructed for ten to fifteen miles in one direction. That part of the lake lying along the International boundary consists of an eastern arm extending from Kettle falls to Brulé narrows, and the southern side of the main part of the lake lying west of Brulé narrows. The eastern arm is twenty miles long (east and west) and from two to five miles wide. The main part of the lake has several large bays running north into Ontario; in fact, most all of this section of the lake lies north of the boundary line. The only extensive bay on the Minnesota side is a shallow body of water lying in the north half of T. 70-22, known as Black bay, or as Rat Root lake by the Indians.

The land surrounding Rainy lake, except on the west, slopes toward the lake, which thus receives the drainage of a considerable area The extent of the drainage basin of Rainy lake is some 16,440 square miles, of which 4,440 are in Minnesota and 12,000 in Ontario. The two most important sources of supply from Minnesota are the waters of the Vermilion river and those of the International boundary chain of lakes. This latter source brings water from both sides of the boundary line for a distance of 150 miles to the east-southeast of Kettle falls, i. e. from the divide between the lake Superior and the Hudson bay drainage in T. 65 N., R. 2 W., Cook county (between North and South lakes). Rainy lake, whose drainage basin is equal to nearly one-fifth of the area of the state of Minnesota, discharges its waters through the Rainy river. This begins at the outlet of the lake in sec. 25, T. 71-24, a locality known as Koochiching by the Indians. Here are two small rapids, with a fall of three feet, beyond which the river flows westward as a stream 600 to 1,200 feet in width to the Lake of the Woods, and from thence the waters find their way into Hudson bay. Two and a half miles west of the outlet are the Koochiching falls where the river plunges over a ledge of rock twenty-one to twenty-four and a half feet high at different stages of water in the river. (See plate II, figure 1.) It is estimated that there are 12,000 cubic feet of water flowing out of Rainy lake every second.

The altitude of Rainy lake has not been definitely determined, but the éstimate of Mr. Warren Upham* of 1,115 to 1,120, or a mean of 1,117 feet above sea level, is probably nearly correct. The greatest known depth of the lake is at a place about six miles north-northwest of the Brulé narrows, where there is the lowest depression in the region, or a depth of water of 110 feet, while the average depth of the lake is probably not far from forty-seven feet.† The accompanying table gives the hights in feet above the sea level of some of the lakes in this vicinity and to the southward. Those marked by an asterisk are accurately determined.

TABLE OF ALTITUDES OF LAKES.

Rainy lake, 1115 to 1120; mean	1117
Kabetogama lake	1125
Namekan lake	1125
Sand Point lake	1126
Crane lake	1126
Little Vermilion lake	1127
Loon lake	1166
Lac la Croix (Nequaquon lake)	1186
Iron lake	1210
Crooked lake	1240
Basswood (Bassimenan) lake	*1300
Vermilion lake	*1357-1360
Lake Superior	*601.56

The Rainy Lake district is of the nature of a plateau with a very gentle slope from all directions, except the west, toward the lake. This plateau, while not having a perfectly even surface, still is not broken by any considerable elevations or depressions, and altogether has a decided flatness. The immediate shores of the lake usually do not rise more than fifty feet above the water, and land 100 feet higher than the lake surface is not common. The highest land in the Minnesota part of this district is just to the south of Kabetogama lake, and the highest elevation in the area mapped is between Open Water narrows and Bear's passage, where a ridge rises about 275 feet above the lake level, or somewhat less than 1,400 feet above the level of the sea. The lowest depression has already been mentioned, 110 feet below the surface of the lake, or 1,007 feet above the sea. The average elevation of the land is probably not more than sixty feet higher than the lake, or 1,175 feet above the sea. A number of soundings made by Dr. A. C.

*Altitudes between lake Superior and the Rocky mountains; U.S. Geol. Survey, Bul. No. 72, p. 188, 1891.

†A.C. Lawson; *op. cit.*, pp. 13 F, 16 F.

Lawson show that the general level of the lake bottom is about as much below the surface of the water as the adjacent land is above it; consequently if land and water areas were in equal amounts the general level of the plateau would be nearly that of the surface of the lake. But, as the land surface much exceeds the water, the average elevation is some feet above the lake level; and it is estimated that the average elevation of the plateau in the area shown on the geological map (plate I) is approximately 1,150 feet above the sea, or 548 feet higher than lake Superior.

The remarkable general flatness of the district is well shown by the large area penetrated by water that stands at nearly the same level. Rainy lake itself, with an extent of forty-six miles east and west and thirty-three miles north and south, may be said to extend through a rectangular area of these dimensions; thus its waters are spread out in various parts of a district including 1,500 square miles, and the general elevation of this rectangular district is not many feet above the lake surface. While just to the south and southeast is a series of lakes, including Kabetogama, Namekan, Sand Point, Crane and Little Vermilion lakes, which have an area probably half as large as Rainy lake and which stand at a level only eight or nine feet higher.

This plateau-like nature of the district will be again referred to in the outline of the geological history of the region, and a possible explanation of the present topography will be suggested.

In its general appearance this district is characteristic of much of northeastern Minnesota; it is a country of lakes, swamps, and timbered rocky knolls. The surface, especially in the district here reported on, is not truly hilly, but mammillated or hummocky. The small knolls that rise above the level of the lakes and swamps are glacially rounded and are covered with only a scant soil, which, however, supports quite a luxuriant growth of pines, spruces, balsam fir, white birch and poplar. The shores of Rainy lake are generally rocky, but toward the western end sand beaches are frequently seen, and the heads of the bays are usually marshy or swampy. Over large tracts there are practically no surface deposits of glacial or more recent origin, the rocks coming to the surface whenever the thin forest soil is pushed aside. The surface is dotted with numerous lakes and lakelets varying in size from an acre to bodies of water a hundred or more square miles in extent. The lakes are largely in completely rock-bound basins and most of

them are elongated in a direction parallel to the trend of the country rocks. From one rocky basin a short, rapid stream carries the water of one lake down to the next lower basin, and in this way the greater part of the drainage is accomplished. Aside from these streams there are over large areas none of any importance and nothing that can be called a river, but wherever the rocks are covered with considerable quantities of drift the lakes become scarcer and the drainage is carried on by the ordinary rivers and smaller streams. The outlets of the lakes are so narrow that, after the melting of the snows and after the early spring rains, the waters are partially dammed back and held at a level four or five, or even ten feet higher than normally.

At the west end of Rainy lake this surface of-lake and rock suddenly gives way to a plain of clays, through which the underlying rock rarely emerges. The change from the rocky lake country to this clay plain is abrupt and very striking, and is intensified by an equally sudden change in the flora; the lake shores and the country to the east have a forest largely of evergreens and boreal in its aspect, while to the west of the lake a forest largely deciduous and more southern in its character appears. The extremely flat surface of the plain is, as far as altitude is concerned, a continuation of the rocky plateau to the east; it has a gentle slope to the west and is unvaried by lakes or other features except the shallow, steep-sided trenches cut by the Rainy river and its tributaries.

II. GEOLOGY.

The rocks underlying this district are among the most ancient known. To a considerable extent they are completely crystalline, and, while many of them bear evidence of having been deposited in water as true sediments, still they offer no trace of any fossils and are regarded by some geologists as older than the earliest life on the globe. From the flat position, in which these strata were originally deposited, they have been elevated, folded and crumpled so that now they stand in abnormal attitudes; and, in addition to the mountain making forces to which these rocks have been subjected, they have been intruded by vast masses of granitic rock. Thus it is difficult to decipher the exact structure of the region. Another cause of this difficulty is the almost universal development, except in some of the granitic rocks, of parallel schistose structures, which are easily mistaken for sedimen-

tary planes and which are not always parallel to these planes, although as a rule in this district the schistose structure coincides in direction with the bedding. The general strike of the rocks is from east and west to east-northeast and west-southwest, but outside of the area shown on the geological map the strike varies much, the rule being that it follows around the outlines of the great granite-gneiss masses of the region.

In age, all of these rocks, with possibly the exception of the diabase dikes whose exact age is unknown, are pre-Cambrian. They are readily separable into four distinct groups. Beginning with the lowest these are: 1. Laurentian, composed of granites and granitoid gneisses and allied rocks; 2. Coutchiching, composed of mica schists grading into fine grained gneisses; 3. Keewatin, composed of hornblendic, greenish and sericitic schists, conglomerates, graywackes, etc.; 4. Diabase dikes, more recent than and cutting all the others. The following table will show the position of these rocks at the base of the geological column, their equivalents in the country to the southeast of Rainy lake and their designations in the terms used by the Geological and Natural History Survey of Minnesota. In the nomenclature of the United States Geological Survey the Keewatin and Coutchiching belong to the Algonkian, and the Laurentian to the Archean or Basement Complex.* In the table the uppermost or more recent rocks are placed at the top.

<table>
<tr><th colspan="3">GEOLOGICAL NAMES.</th><th>RAINY LAKE DISTRICT.</th><th>EQUIVALENTS TO THE SOUTHEAST.</th></tr>
<tr><td rowspan="2">PALEOZOIC</td><td rowspan="2">TACONIC</td><td>Keweenawan</td><td>Diabase dikes?</td><td>Copper-bearing rocks of lake Superior.</td></tr>
<tr><td>Animikie</td><td>(Wanting)</td><td>Iron ores and other rocks of the Mesabi range.</td></tr>
<tr><td rowspan="3">ARCHEAN</td><td rowspan="2">ONTARIAN</td><td>Keewatin</td><td>Greenish and sericitic schist, conglomerate, graywackes, etc</td><td>Iron ores and other rocks of the Vermilion range.</td></tr>
<tr><td>Coutchiching</td><td>Mica schists and fine grained micaceous gneiss.</td><td>Crystalline schists on both sides of the Vermilion range.</td></tr>
<tr><td colspan="2">LAURENTIAN including eruptives.</td><td>Granites and gneisses.</td><td>Granite and gneisses of Vermilion and Basswood lakes.</td></tr>
</table>

*More information concerning the designations and relations of these ancient rocks in Minnesota and their equivalents in adjacent territory can be gained by consulting the table of the "Pre-Silurian Rocks of Minnesota," which faces page 4 of the 21st (1892) Ann. Rept. Geol. and Nat. Hist. Survey of Minn., 1893.

The Rainy Lake district has no rocks more recent than these ancient Archean ones, but scattered over the surface are small deposits of glacial drift, and just west of the lake, as has already been mentioned, is a considerable thickness of clays.

*The Laurentian.**

The Laurentian is composed entirely of completely crystalline rocks,—granites and syenites with gneisses of the same mineralogical composition. The extent of territory covered by such rocks in northern Minnesota and adjacent portions of Ontario is surprisingly great. Nearly a third of the region here reported on is underlain by the Laurentian, while all the shores of Rainy lake north of the area shown on the geological map are composed entirely of these same rocks. Contrary to expectation these hard granitic rocks do not always form pronounced hill ranges, as is the case with the Giant's range of granitic hills on the northern flank of the Mesabi iron range, but very frequently these areas of Laurentian rock give a comparatively level surface on which are extensive and extremely irregularly outlined bodies of water. Examples of these spider-like lakes stretching over considerable areas of granite can be seen in Saganaga, Basswood (Bassimenan) and Crooked lakes, and in Lac la Croix and a large portion of Rainy lake itself.

In color the Laurentian rocks are white, gray, pinkish and reddish, the prevailing color in any one place being largely due to the color of the most important mineral,—the feldspar. In grain these rocks vary from those in which the individual minerals can scarcely be recognized with the naked eye, to very coarse aggregates where some of the feldspar crystals are several inches across. Most of these rocks can be called granites, *i. e.*, they are granular aggregates of quartz and feldspar with a dark mineral, either black mica (biotite), hornblende or augite. Sometimes two of these are present, and in other places, especially in the coarse grained dikes or veins which occur in the mica schists, white mica (muscovite) is the only mineral present in addition to the quartz and feldspar. The quartz fre-

*In this report the term *Laurentian* is used to include all the gneissic and granitic rocks of the Archean in this region. That many of these rocks are of later date than and intrusive into, parts of the Coutchiching and Keewatin, is well known; but, as such rocks have generally been mapped and described as Laurentian in the previous reports of the Minnesota survey, and as they have been also described under this term by Lawson in his well known writings on the geology of that part of Ontario lying immediately to the north of Minnesota, and as such rocks are generally known as Laurentian, the writers have thought best to retain this term in the present report, even though this usuage is, in part at least, a violation of the idea of Laurentian used strictly as an age term.

quently diminishes in quantity and even completely disappears; such a rock with no quartz, or a very small amount of it, is known as syenite. In fact all the minerals vary greatly in amount in the different parts of one rock mass. For example, a rock in a certain place composed of quartz, feldspar and hornblende will vary by a gradual decrease of the hornblende until almost none is left, and we have a rock composed almost entirely of quartz and feldspar; or, as the hornblende decreases, mica or augite may increase and we have a change from a hornblende granite to a mica or an augite granite. The only mineral which is prevalent throughout the whole of the Laurentian is feldspar, and even this varies greatly in amount within small distances.

In structure, also, the Laurentian rocks differ considerably. The granites and syenites are sometimes massive in appearance, *i. e.*, they exhibit no schistose or laminated structures; the structure is granular, and every part of an exposure is like every other part, except perhaps as regards the relative proportions of the different minerals or the fineness of the grain. But this massive appearance is by no means prevalent throughout the whole region; it generally gives place to a somewhat schistose or foliated structure. Some of the minerals of the granite or syenite are often seen elongated or flattened in one direction; this is especially true of the mica. When this is the case the rock breaks more easily along the planes in which these crystals lie. Or the rocks may be crossed by narrow streaks which are composed largely of one mineral with the longer diameters of many of the crystals lying roughly parallel. At other times certain bands, one to three or more inches wide, will be seen running through the rock, each band being of a somewhat different composition or texture from the adjoining ones. These foliated and banded rocks are known as gneisses, and in this region they can be conveniently designated as granite gneiss or syenite gneiss, depending upon whether the mineralogical composition is similar to that of granite or syenite. These various features of the Laurentian rocks allow them to be separated into different classes or groups both mineralogically and structurally, but these groups are frequently seen grading into each other. The hornblende granite of one point will pass gradually into a hornblende syenite near by, and this again may change to a mica syenite. Again, a perfectly massive rock will become foliated within a short distance, the intervening steps between the massive and the fo-

liated or gneissic rock being readily traceable. It thus is often impossible to draw a line between the various phases of these Laurentian rocks; consequently in the geological map no attempt has been made to separate the different varieties. It is unnecessary to describe all the outcrops of these rocks, or to indicate the areas occupied by each of the different groups, but a brief account of a few of the more interesting or typical occurrences will be given below.

At Koochiching falls the rock is a medium gray biotite syenite; the component minerals are white feldspar and biotite, with a little hornblende and epidote. This syenite is massive in some places, but usually shows a slight indication of a foliated or gneissic structure, thus approaching a biotite syenite gneiss. It contains many darker masses, sometimes a foot or more in diameter; they are composed of the same minerals as the main part of the rock, but the mica makes up a very large proportion of each dark mass. These darker masses can be referred to fragments of foreign rock included in the syenite, or to segregations of the basic minerals of the syenite itself. This medium grained gray biotite syenite is the usual phase of the rock at the falls. It is especially well shown in the rocks thrown out from an excavation for a canal at Fort Frances made by the Canadian government some years ago. Below the falls the rock becomes porphyritic with crystals of flesh colored feldspar which are often an inch in length. These crystals stand out all over the weathered surfaces of the rock. Two islands about three-fourths of a mile below the falls contain excellent exposures of this rock; the upper of these islands is composed of syenite alone, while the lower also shows a fine micaceous schist, which, in places, is seen in sharp contact with the syenite; and in other places there is apparently a transition from the syenite to the mica schist within a distance of a few feet.* Along the river above the falls on the Canadian side no outcrops were seen, but two exposures of the syenite occur on the Minnesota side; the first of these is in the town of Koochiching about where the north line of sec. 34, T. 71-24 cuts the shore, and the second is near the center of the N. ½ of N. W. ¼ sec. 35, T. 71-24. At the latter outcrop the rock is porphyritic with feldspar crystals, most of which are bright red in color, while a few are greenish.

In the N. E. ¼ of sec. 28, T. 71–23, in Rainy lake, is an island elongated in a north and south direction, while just a few

* 17th (1887) Ann. Rept. Geol. and Nat. Hist. Survey of Minn., pp. 410-412, 1888.

yards to the southwest is another and smaller island on which the usual relations of the Coutchiching mica schist and the Laurentian granite are clearly and unmistakably shown. The latter rock forms the northeast side of this little island and the former the southwest side; along the center of the island the two are in contact. The granite is a light gray rock of medium grain, composed of white feldspar, which is probably largely orthoclase, quartz and biotite. There is sometimes a sub-porphyritic aspect due to the existence of a few crystals of feldspar larger than the other crystals of the rock. There is also an indication of a foliated structure caused by an indistinct streaming of the biotite and an elongation of some of the feldspars in one direction. This is not pronounced enough to strictly allow the application of the term gneiss, and the rock may be called simply a granite, or a gneissic or gneissoid granite if it is desired to make the existence of an indistinct foliation prominent. This partial foliation agrees in strike and dip with the mica schist which stands nearly vertical and trends 50° to 60° east of north. At the contact line, which roughly follows the direction of the strike, the granite is not particularly finer grained, nor does it differ otherwise from its normal condition. A few angular fragments of mica schist are to be seen entirely surrounded by the granite, and in the mica schist are irregular vein-like forms or dikes running both across and along the beds of mica schist; some of these dikes can be traced directly into the main mass of granite. They are of all sizes from a fraction of an inch to several feet in width. A hand specimen collected to illustrate the contact shows a small stringer of granite, one-fourth of an inch wide, which starts out from the main mass of the granite, runs for two inches in the mica schist and then gradually thins out and disappears. The relations of these two rocks show conclusively that the granite here acts as an eruptive rock and that it has been forced, while in a plastic or fluid state, into cracks or fissures in the mica schist. At the contact the mica schist does not appear much different from the same rock a short distance away, but it is harder and less schistose, and microscopical examination would probably show some mineralogical changes due to the heat of the granite. Another interesting feature on this small island is the occurrence of small dikes of a finer grained rock which cuts the granite itself and is therefore of later date. This rock is a very fine grained white granite composed almost entirely of quartz and feldspar;

it cuts the main granite in numerous small dikes which are two feet or less in width. These dikes are not finer grained at the edges than at the centers, and they do not exhibit any foliation; there is nothing to show definitely how much later these dikes are than the main mass of the granite, but it is probable that the two rocks do not differ much in age. One dike of this fine grained white granite (or aplyte) was seen in the mica schist.

Three-fourths of a mile east of these islands, on the blunt point near the center of the north side of section 27, T. 71-23, the granite and mica schist are again seen in contact. Here the granite exists commonly in thick bed-like forms between the layers of mica schist, but in many places these "beds" are seen to be directly continuous with other masses of granite that cut directly across the beds of mica schist. The contact of these two rocks can also be seen on the island in the S. E. ¼ of sec. 22, T. 71-23.

It is not uncommon to find in the mica schists large veins or dikes of very coarse grained rock of a composition similar to the granites. In such places the individual crystals often reach a length of several inches. The minerals of these coarse grained rocks are feldspar, which is usually pinkish or reddish and is either orthoclase or microcline, quartz, and most commonly muscovite. The quartz and feldspar are often grown together in such a manner as to form graphic granite, *i. e.*, a certain large mass of feldspar, which is shown to be all one crystal by the extension of the same cleavage plane through it, is spotted all over by smaller grains of quartz; and each quartz grain, when studied under the microscope, is seen to have the same crystallographic axes as the other grains in the same feldspar crystal, showing that these grains are really all parts of the same quartz crystal. Perhaps a good illustration of this growing together or interpenetration of feldspar and quartz can be had by likening the feldspar crystal to a sponge full of cavities, which cavities have all been filled by a continuous mass of quartz. Rocks of this nature are quite common along the shores of Kabetogama lake, and to the south and east along the International boundary. The individual crystals of feldspar often reach surprising dimensions. For instance, in one place a crystal was seen which measured actually thirty-three inches in length, and many were found over a foot long. The locality where this large crystal occurs is on the point which is at the center of the W. ½ of S. E. ¼ sec. 19, T. 70-18,

on the south shore of the eastern arm of Rainy lake. Here this coarse grained rock, which is often known as pegmatyte, forms large veins or dikes in the mica schist. Sometimes these pegmatyte forms occur in the granite itself.

A short distance northwest of Shoal lake are gold bearing veins in an area which has been mapped as granite. The rock in which the veins occur is somewhat different from that seen elsewhere, and, as it has been called by various names, we have endeavored to make a rather careful examination of the specimens we have of this rock in order to determine, if possible, just what the rock is. As just stated, this rock has been called granite, and there are areas in the midst of the rock which hold the veins that are true granite and which do not seem to be sharply separated from the vein-holding rock. A description of a specimen from one of these granitic areas on Wiegand's location, A L 75, is as follows:

Macroscopically this rock is a gray granite of medium grain, and quite fresh. The minerals are quartz, feldspar and biotite; the first two are in approximately equal amounts and compose three-fourths to five-sixths of the rock. The feldspar is whitish, varying to greenish and pinkish, the latter shade apparently due to iron staining.

Under the microscope the structure of the rock is seen to be truly granitic. In addition to the minerals mentioned above are small flakes of muscovite and a few greenish areas composed of chlorite. The quartz is ordinary granitic quartz containing bubbles and gas cavities. It shows undulatory extinction, and frequently a large grain has been fissured into many smaller ones which, however, have not been separated from each other and so extinguish at almost the same time. Undulatory extinction and this fracturing of the grains are the effects of pressure on the quartz, which mineral is one of the first to show the effects of having been subjected to pressure, especially when enclosed in a hard solid substance like granite. The feldspar is highly altered, largely to a mass of brightly polarizing flakes and fibres which seem to be muscovite. In some grains a trace of polysynthetic twinning still remains, and undulatory extinction is present. The feldspar was originally orthoclase and an acid plagioclase apparently of the albite-oligoclase series.

To sum up, this rock is a typical medium-grained biotite granite, or granityte, with the feldspar considerably altered; the rock has been subjected to pressure, as shown by the

fracturing of the quartz and the undulatory extinction of both quartz and feldspar, but no schistose structure can be seen either in the hand specimen or in the slide.

The rock in which the veins occur at Wiegand's location, A L 75, is a peculiar greenish gray rock composed of quartz grains imbedded in yellowish green groundmass. The quartz is in glassy grains of all sizes up to those one-fourth of an inch across; some of the grains are pinkish, due to iron staining. The groundmass is too fine grained to allow its constituents to be distinguished by the naked eye; it appears homogeneous, is soft, has a greasy feel, can be readily scratched with a knife and effervesces slightly with cold hydrochloric acid. A slight schistose structure can be distinguished in the ground mass. A few grains of pyrite occur, but fully a third of the rock is quartz.

The thin section shows a number of quartz grains of various shapes and sizes imbedded in a groundmass of minute fibers. The quartz shows undulatory extinction and fissuring to a better degree than in the granite just described. A few small flakes of muscovite are present, also a small amount of calcite and an opaque yellowish substance. The fibers of the groundmass are quite small and polarized in rather bright colors; they are muscovite or sericite. Mixed in with the fibers are very minute grains of quartz and perhaps also some of feldspar. At places in the groundmass are irregular areas and shreds of feldspar; often these have a few flakes of the mica in them and their edges are jagged, due to a penetration of the fibers into the feldspar substance. Frequently several areas of feldspar in the same vicinity extinguish together, showing that they are remnants of an originally larger grain which has passed almost completely into mica. The fibers of the groundmass are often elongated in one direction; this causes the schistose structure of the rock.

As to just what this rock was originally, it is hard to make a positive statement. That it has been subjected to pressure and shearing is evident from the condition of the quartz and the schistose structure of the rock. It is also evident that some parts, at least, of the groundmass are due to a breaking down of feldspar grains, the remnants of which are still present; it is not improbable that most of the groundmass has a like origin. While all the field relations of this rock are not known, still it occurs in an area of rock in which are parts that are certainly granite, as that just described, and it does not seem to

be sharply separated from these certainly granitic areas. The quartz grains are very similar to those in the granite above described. Thus it seems possible, and indeed probable, that the rock under consideration was originally a granite, and that it has been subjected to pressure and shearing, which have induced the schistose structure, and which, with the aid of percolating waters and perhaps heat also, altered the original minerals (excepting the quartz) to the present fibrous groundmass. The quartz shows fracturing and undulatory extinction, but is otherwise unaltered as it is almost indestructible when compared with the other minerals of the granite. That the rock might have been other than a granite it is impossible at present to deny; there are, however, no characters that necessarily indicate another origin. The original nature of the rock can be determined only by a careful investigation of the field relations supplemented by microscopic evidence. But from our present knowledge we would consider this rock as most probably an altered phase of granite.

The exact nature and origin of these Laurentian completely crystalline rocks in the Rainy Lake region and elsewhere are rather complicated questions and can not yet be settled to the satisfaction of all who have studied them. That these rocks in the region here considered are now totally lacking in characters that clearly show them to have once been clastic like ordinary sediments goes without saying. And there is no positive proof that the more pronounced gneisses,—those that show alterations of bands of different mineralogical or structural characters, which varieties of gneiss are not common,—were once sedimentary, although the presence of this banding and other less pronounced foliation is to some a strong argument for an originally sedimentary nature. That these granitic rocks are intrusive in numerous places into the Coutchiching mica schists, and often into the Keewatin rocks, is absolutely certain. Good proof of the metamorphism of the clastic rocks of the region to form gneisses has not yet been observed, although places that show this may be found in the future. Dr. A. C. Lawson, who is familiar with this region, thinks that these Laurentian rocks represent older rocks than the Coutchiching, but whether originally sedimentary or not is only to be guessed at; they have been softened and fused and while in this condition have been intruded into the rocks lying above them and there solidified. The following quotation from this author will help to explain his view:

This group of crystalline rocks, granites and syenites, foliated and non-foliated, forms the floor of the region upon which rest all other formations that are not in the condition of dykes or intrusive bosses. Regarded as a geological system of rocks it occupies an apparently paradoxical and anomalous place in any scheme of classification. As the floor or basis upon which the geological column of stratiform rocks rests, it must be regarded as the first or fundamental system of rocks of which we have any cognizance. If, however, we inquire as to the age of these rocks, we are forced, by the direct application of the simplest principles of geological science to look upon them as of later age than certain of the series which overlie them. We do not yet know their original condition prior to the fusion from which they solidified into granites, syenites and gneisses. They may have been sedimentary; they may have been the original crust of the earth. The abstract speculations that are so often indulged in on this and similar questions have not decided the facts of the matter. There is yet no sufficient ground for a just opinion upon it. But whatever may have been that original condition the evidence is clear on this point, viz: that the fusion and solidification, whereby they were brought into their present condition as firm crystalline rocks, took place at a period subsequent to the existence, in a hard, brittle condition, of the stratiform and often very distinctly clastic rocks which occupy a higher place in the column. Therefore, as rocks, the members of this fundamental system are of younger age than that of the nearest overlying formations. An analogous case with which every geologist is familiar is that of dykes. These are of younger age than the strata they cut, although the main mass, of which they are merely the apophyses, is far inferior to those strata and may form the base upon which they rest.*

Under this view, concerning the Laurentian, the floor on which the Coutchiching rocks, and in some places the Keewatin, were deposited is now entirely unrecognizable; it has been softened and moved so that its relation to the Coutchiching is now an eruptive one. On the other hand, it seem probable that parts of this old floor are still preserved; such places, however, have not yet been found in this locality, all the granite and gneiss areas examined apparently showing an eruptive relation to the Coutchiching; and the same can be said of the relations of the granite and gneiss to the Keewatin. However, to the northeast of Rainy lake, rocks apparently corresponding to the Keewatin have been found unconformable upon an older series of granites and gneisses† supposed to represent the Laurentian; and it is not impossible that the Keewatin conglomerate seen on the north of Shoal lake will be found to be unconformable on the granite to the north. Many problems concerning these ancient rocks,—Laurentian, Coutchiching and Keewatin,—especially as regards their relations to each other,—are still unsolved, and it will not be profitable to discuss them further here.

* American Journal of Science, 3rd series, vol. 33, pp. 474-475, 1887.

† H. L Smyth; Structural geology of Steep Rock lake, Ontario; Amer. Jour. Sci., 3. vol. 42, pp. 317-331. pl. 11. 1891.

The Coutchiching.

This series of rocks, while occupying a large amount of territory, is of comparatively simple character and will need but a brief description. They extend along the south shore of Rainy lake from the outlet east to Jackfish bay, then for a distance of eight miles (to the line between Itasca and St. Louis counties) the Keewatin occupies the shore, but all the south shore east of this and all the shores of the eastern arm of the lake, with the exception of a few granite areas, lie entirely in rocks of this series. Other small areas are found to the north of the belt of Keewatin rocks that runs east-northeast from Jackfish bay.

Lithologically the Coutchiching is preëminently a mica schist formation; with the mica, which is mostly biotite, is either quartz or feldspar, and commonly both in the more coarsely crystallized facies. The rocks near the outlet of Rainy lake are mostly quite fine grained mica schists or even gray to brownish mica slates, but usually the Coutchiching rock is a well defined mica schist. In close proximity to some of the granite masses, as along the north shore of Kabetogama lake, the mica schist becomes quite coarsely crystallized and might properly be called a gneiss, but it is not easily confounded with the gneisses of the Laurentian. In addition to the usual minerals, others, such as garnet and staurolite, are sometimes found in the mica schists not far from their contact with masses of granite. The schistose structure, due to an arrangement of the mica scales in roughly parallel positions, is characteristic of this series. In many places there are rapid alterations of bands, from an inch to several feet in width, of slightly different mineralogical composition, structure or color; the position of these bands gives the strike and dip of the rock, and where they are lacking the schistose structure is taken to indicate the strike and dip, as this structure seems to be parallel with the banding wherever the two are seen together. There is a vast thickness of this monotonous mica schist formation along the eastern arm of Rainy lake and to the southward; several estimates by Dr. A. C. Lawson show an apparent thickness of about five miles.* These Coutchiching rocks in several particulars appear so much like ordinary sediments that it seems necessary to consider them as sedimentary beds which have been more or less recrystallized in situ by metamorphic processes. This change has been largely in the nature of regional

* Geol. and Nat. Hist. Survey of Canada, new series, vol. 8, pp. 101-102 F. 1889.

metamorphism, but the more coarsely crystalline condition of the beds in close proximity to intrusive masses of granite shows that contact metamorphism has also played an important part.

The relation of the Coutchiching to the Laurentian has already been mentioned. Its relation to the Keewatin is not definitely known. The Coutchiching, however, is lithologically quite distinct from the overlying Keewatin rocks, and in the field it is a comparatively easy task to separate these two series of rocks. Where they are in contact, however, they have the same strike and dip and thus appear strictly conformable. But the difference in lithology between the Coutchiching and Keewatin is marked; in the former we have no evidence of volcanic activity, while in the latter there are numerous proofs of great volcanic activity, in fact, the Keewatin can be said to be characterized as a period of intense and wide spread eruptions. Moreover, in the Keewatin are conglomerates, which, in places, seem to be basal beds resting on the Coutchiching. Lawson * has consequently inferred an unconformity between these two series, and while the existence of this is not undoubtedly proven, it still seems quite probable.

The Keewatin.

This series of rocks is more varied in lithology than either of the others just described, and it is of more interest on this account and also because in it are found most of the gold bearing veins thus far discovered. The rocks are conglomerates, slates, sericitic, chloritic and hornblendic schists, agglomerates, graywackes and more or less altered igneous rocks, both acid and basic. The presence of large amounts of hornblendic and other green schists, some of which are clearly of igneous origin, gives to this rock series a prevalent green color, and this abundance of "greenstones" and "green schists" is one of the most characteristic and distinctive features of the Keewatin series. That parts of these green rocks represent ancient igneous ejections, both lavas and ash beds, is absolutely certain; and, as before stated, they show that the Keewatin was a time of violent and extensive volcanic activity. But the Keewatin was also a time of deposition for ordinary sediments. Much of the fragmental volcanic material seems to have been deposited in water, which has given a stratiform character to the beds, and mixed with this fragmental igneous matter was more or less of

* *Op. cit.*

ordinary sediments; the two kinds of deposits evidently grade into each other, the igneous material predominating in close proximity to volcanic vents. These Keewatin rocks, like the other series, have participated in great earth movements, which have produced slaty and schistose structures. The effects of these movements seem to have been better registered in the Keewatin rocks than elsewhere by a more pronounced and almost universally present schistose cleavage.

The most important belt of Keewatin rocks is that which is first seen on the south shore of Rainy lake at Jackfish bay. West of here this belt has not been carefully traced out, but a few outcrops have been seen, some of which will be mentioned below. East of this bay the Keewatin forms the south shore of the line between Itasca and St. Louis counties; and a number of islands just to the north of the shore, the largest of which are Grassy, Grindstone, Dryweed and Sand Point, are mostly composed of the same rocks. This belt of Keewatin runs a little north of east, crosses the lake and extends past Seine bay and Shoal and Bad Vermilion lakes and eastward beyond the limits of the map.

To the west of Jackfish bay sections were made south from Rainy river in two places. The first was along the west line of sec. 35, T. 71-24, and southward for a mile and a half beyond the south line of this section. No outcrops were seen; the ground passed over is nearly level and forms a part of the clay plain which lies along the river. However, in the S. E. ¼ of S. W. ¼ of this same section there is an exposure of considerable extent which rises a few feet above the level of the plain. The rock is a fine grained gray sericitic schist or slate with no pronounced lines of sedimentation. The cleavage, as measured in three places, runs N. 50° E. (mag.) and stands about vertical. Parallel with the cleavage are fine laminæ which, in the absence of more definite indications, are assumed to represent the true sedimentary planes of the rock. The second section was made from the lake shore at the outlet, along the east line of range 24, to a point half a mile south of the southeast corner of T. 71-24. Several outcrops were crossed, all of which present a schistose cleavage that runs N. about 50° E. (mag.) and dips at a high angle toward the northwest. In some places a distinct alternation of beds of different composition was seen; these give the true strike of the rock which, as far as seen, coincides with the cleavage. The rock of these outcrops is largely a sericitic schist, but it frequently

becomes darker colored and greenish and contains minute laminæ of white siliceous material.

On the south shore of Jackfish bay and on an island in this bay near the west line of sec. 26, T. 71-23, are excellent exposures of conglomerate. The conglomerate of this island, which is made entirely of this rock, has as a matrix a greenish to grayish fine grained schistose rock composed of silvery micaceous scales and other material which is too finely divided for recognition by the naked eye. In some places the matrix becomes coarser and is crowded with quartz grains the size of a pin's head and larger. The pebbles of the conglomerate are very numerous and are well distributed throughout the rock of the island; they vary in size from pieces the size of a pea to those that are ten inches across. Several kinds of rock are represented in these pebbles, but the most common is white or yellowish vein quartz; next in abundance are pebbles of a gray rock which seems to be a very fine grained granite. Pebbles more or less similiar to the matrix are also common; these are not easily recognized on fresh fractures, but on weathered surfaces they are quite readily distinguished. The pebbles are mostly well rounded; this is especially true of those composed of quartz, which are very sharply separated from the matrix and can be easily dislodged. The conglomerate has been subjected to shearing and stretching and as a result the pebbles are commonly seen flattened in one plane, which coincides in direction with the schistose cleavage of the matrix. The strike of this cleavage is N. 60-65° E. (mag.) and the dip is about vertical. In a few places there are some indications that the true strike of the conglomerate is almost at right angles to the strike of the cleavage; these indications, however, are not entirely satisfactory evidence of the position of the bedding, nor are there satisfactory evidences that the true strike is parallel with the cleavage. On the south shore of this bay are other outcrops of the conglomerate, the matrix at this place being a green schist. Small pebbles are not common here, most of those seen being over six inches in diameter; sometimes they reach a size of three feet in greatest diameter. These boulders are largely of one rock—a rather fine grained greenish to pinkish biotite granite. They are well rounded and lie with their long axes parallel with the strike, which is here plainly coincident with the schistose cleavage.

Other exposures of conglomerate occur to the east of Jackfish bay on the south shore in the N. ½ of sec. 31 and the S. ½ of sec. 30, T. 71-22. Here the matrix is a green hornblende schist, more or less siliceous. The pebbles are mostly of about the same nature as the matrix and are distinguishable only on weathered surfaces. They have been elongated in a direction parallel with the cleavage and on this account and also because they so closely resemble the matrix, it is hard to tell whether they originally possessed rounded outlines or not. However, a few boulders occur at this place, which are of rock similar to the granitic boulders in the exposures on Jackfish bay, and they are distinctly and smoothly rounded.

On the south shore of Dryweed island in sec. 25, T. 71-22, the rock of the island, which is a sericitic schist, becomes conglomeratic with granitic boulders similar to those just mentioned.

Another belt of conglomerate is seen along the north side of Grassy and Shoal lakes. The specimens we have of this show the matrix to be a rough green hornblendic schist, sometimes quite rich in large and small grains of quartz. The pebbles are of greenstone, black and red jasper, quartz and felsyte, many of them being well rounded. Just northwest of Shoal lake this conglomerate is found resting directly upon the granite mass of Bad Vermilion lake. The exact contact line is exposed for some distance, and small patches of the conglomerate, which are easily dislodged are found lying directly on the surface of the granite. Although a casual examination failed to find any pebbles in the conglomerate that could be certainly referred to the underlying granite, still the relations of the two rocks at this place seem to indicate that the conglomerate is unconformable on the granite.

Another typical rock of the Keewatin series is seen in the S. ½ of sec. 29, T. 71-22. The conglomerate to the west of this gradually loses its greenish character and becomes lighter colored and siliceous on going eastward; at the same time the boulders become less numerous and finally disappear altogether, and we have a rock that is fine-grained, hard, tough, siliceous, and silvery gray in color. This rock forms bare, rounded knobs in sec. 29 and is quite massive in appearance. It continues eastward to form Grindstone and Dryweed islands, but on these islands, especially the latter, it becomes softer and more schistose, forming a siliceous sericitic schist. It also in places shows evidences of bedding which is parallel with

the schistose structure, and, as mentioned above, it becomes conglomeratic on the south shore of Dryweed island in sec. 25, T. 71-22.

Just to the south of this belt of siliceous sericitic schist lies a belt of greenish schists, which are of interest for the reason that in them are found the veins that have been most exploited for gold. This belt of rock comes to the shore in the N. E. ¼ of N. W. ¼ of sec. 32, T. 71-22, and continues eastward forming the islands in the N. ½ of N. W. ¼ of sec. 33, the most easterly of these islands being the one on which the Little American mine is located. The south shore of the lake eastward from Rainy Lake City to the line between Itasca and St. Louis counties is skirted by this belt of rock, and the islands in the S. E. ¼ of sec. 27, the S. E. ¼ of sec. 26, the S. ½ of sec. 35, T. 71-22, and some small reefs near the center of sec. 30, T. 71-21, are composed of the same. This belt of schists varies somewhat in lithology, being composed of sericitic, chloritic and hornblendic schists, which are quite fine grained and usually quite siliceous. The smaller and more eastern of the islands in the S. E. ¼ of sec. 26 has a small amount of more acid and lighter colored rock than is usual in this belt. This rock consists of scattered quartz grains imbedded in a siliceous and schistose matrix; it perhaps represents an ancient quartz porphyry.

Further mention and description of parts of the Keewatin will be found in the section entitled "Description of veins in general and of individual properties."

The diabase dikes.

These are not very numerous in the area here reported on, and the total amount of such rock is very insignificant when compared with the rocks of the three series already described. The dike rock is dark, tough and heavy; it varies much in grain in the larger dikes according to the distance from the dike walls, the interior being coarser than the exterior. The rock is usually an ordinary diabase, with the ophitic structure, and is composed essentially of augite and plagioclase feldspar. Several dikes were seen in the syenite a short distance below Koochiching falls, and a larger one occurs in the same rock in the N. W. ¼ of sec. 35, T. 71-24. The largest dikes seen are those near the mouth of Jackfish bay; while these two are not strictly parallel, they both have a general northwest-southeast direction. The more eastern of these cuts through rocks which

belong to the three rock systems of the region. The exact age of these dikes is not known. They are, however, later than all the other rocks of the region which they cut, and they have not been subjected to the same forces which produced so pronounced cleavages in the older rocks. During the Keweenawan time there were great numbers of basic eruptions and injections in the Lake Superior basin, and the dikes of the Rainy Lake region may perhaps date from the same time.

Glacial deposits.

As has already been stated, the rocks around Rainy lake are usually not covered by glacial drift or later deposits. In some places, however, there are small areas where there are thin sheets of till concealing the bed rock, and glacial boulders are common throughout the whole region. The general direction of glacial movement across the Rainy Lake basin, as shown by scratches on the rocks, was from northeast to southwest. Below are given a few heretofore unpublished courses of glacial striæ in the Rainy Lake region referred to magnetic north.*

Center of W. side of S. E ¼ sec. 19, T. 70-18, S. shore of Rainy lake	S. 30-35 W.
N. E. ¼ N. W. ¼ sec. 30, T. 71-23, S. shore of Rainy lake	S. 30 W.
W. line of sec. 29, T. 71-23, S. shore of Rainy lake	S. 40 W.
S. W. ¼ S. W. ¼ sec 29, T. 71-22, S. shore of Rainy lake	S. 45 W.
N. W. ¼ S. E. ¼ sec. 28, T. 71-22, E. end of Grindstone island, Rainy lake	S. 33 W.
N. W. ¼ N. W. ¼ sec. 30, T. 71-21, small island at E. end of Dryweed island, Rainy lake	S. 42 W.

The level area devoid of rock which begins at the west end or the outlet of Rainy lake, is underlain by a considerable thickness of glacial deposits. These deposits consist of clays, which are often calcareous and sandy and are quite frequently bluish in color. Scattered throughout these clays are small pebbles of various kinds of rocks, the most common of which is a fine grained yellowish or pinkish limestone; sometimes fragments of this limestone are found which contain a few fossil remains. These clays are thought to have been deposited from melting ice and from streams flowing into the glacial lake Agassiz. This lake covered the Red river valley, the Lake of the Woods and Rainy lake areas, and a large amount of territory to the west and northwest at the close of the Glacial per-

*Other lists of glacial striæ in this region have been published by A. C. Lawson (Geol. Surv. Canada, vol 3, pp. 164F-169F, 1889); H. V. Winchell (Minn. Geol. Survey, 17th Ann. Rept., 1888); Warren Upham (Minn. Geol. Survey, 22d Ann. Rept., pp. 35-40, 1894.)

iod; the history and deposits of this great glacial lake have been carefully investigated by Mr. Warren Upham.* The thickness of the clay deposits along that part of the Rainy river shown on the geological map probably does not much exceed forty feet; in general, the hight of the river banks above its bed is a direct measure of the thickness of the clays.

There are no post glacial formations in the region except the usual soil, vegetable accumulations in swamps, and a few sand beaches, mostly derived from the clays by the washing and sorting action of the lake's waves.

Auriferous gravels forming placers are not known about about Rainy lake. Some search for placers has been made, but there seems to be no probability that any will be found.

Auriferous gravels may have existed in some of the old water courses just before the Glacial period, but if they did thus exist, which is improbable; they were entirely removed by glacial agencies. Since that time there has been no erosion violent enough to produce any gravel deposits. To be sure, gravels can be found in some of the depressions, but these are of glacial origin, and consequently are not necessarily derived from the auriferous rocks near at hand, but may have been and probably were transported many miles; moreover, in the glacial gravels there has been no assorting of the various constituents and concentration of the heavier portions, and so the gold, if it does exist in the gravels, is scattered through them indiscriminately and in such minute quantities as to preclude the possibility of profitable working.

Sketch of the geological history.

The oldest sedimentary rocks of which we have knowledge in the Rainy Lake region are the mica schists of the Coutchiching, but what composed the surface upon which these rocks were deposited is now unknown. An immense thickness of nearly uniform deposits was built up during Coutchiching time, and at the end of this period of deposition there was possibly a period of cessation of deposition accompanied by elevation of the land above the sea level and by erosion. But whatever the events at the close of the Coutchiching, we know that at the beginning of the Keewatin time there was a change from the deposition of uniform rather acid rocks to deposits of the most

* Geol. and Nat. Hist. Surv. of Minn., 11th (1882) Ann. Rept., pp. 137-153, 1884. Ibid., Final Rept., vol. 2, pp. 517-527, 1888. U. S. Geol. Survey, Bull. 39, 1887. Geol. Surv. of Canada, Ann. Rept., new series, vol. 4, pp. 1E-156E, 1890. Also in a forthcoming monograph of the U. S. Geol. Survey entitled "The Glacial Lake Agassiz."

varied nature, in which basic volcanic material played an important part. The Keewatin was a period of rapid deposition and wide spread volcanic activity. After the end of Keewatin deposition there was a period of elevation and intense folding, crumpling and shearing of the then existing strata, accompanied by the intrusion of enormous masses of granitic rock. The rocks were much altered or metamorphosed at this time by the dynamic forces to which they were subjected and also by the close proximity of large masses of intrusive rock; thus the strata underwent regional metamorphism, more or less pronounced throughout the district, and contact metamorphism where intruded by the granitic masses. We know that the folding and alteration took place in post-Keewatin time, and, from the relations of similar rocks to the Animikie southeast of Rainy lake, we suppose that it occurred in pre-Animikie time. This period of folding and alteration probably left the strata in approximately the same position and crystalline condition as we now find them. The accompanying cut (fig. 1) will show the general relations of the rocks of the Rainy lake region after this period and after the erosion to which they have been subjected up to the present time.*

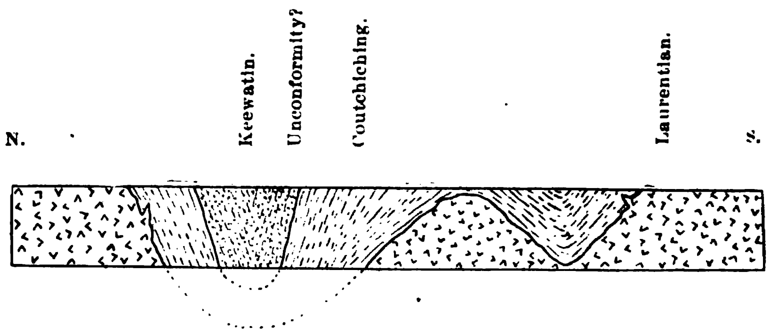


FIG. 1.—Generalized section north and south through the Rainy Lake region.

Some time after the events just spoken of, possibly in Keweenawan time, the rocks of the region were cut by the diabase dikes.

From the end of the Keewatin time to the present we have no proof that the land has ever been below sea level nor that it has ever been covered by post-Archean deposits, excepting, of

* It is quite probable that on future study, after carefully plotting the dips and strikes, the folding of this region will be found to be much more complex than this generalized cut indicates. For instance, what is represented as a single syncline in the Keewatin may really consist of several closely compressed synclines and anticlines. But as yet data are not at hand to show the existence of these numerous smaller folds.

course, the deposits of the Glacial epoch. It is possible that the Cretaceous ocean may have extended over this region, as strata of that age are found in northern Minnesota along the Big and Little Fork rivers and on the Mesabi iron range.* If such strata ever did exist in the Rainy Lake district, all traces of them have been removed by erosion.

From Keewatin time to the present, through all the immense period during which in other places were deposited the rocks of the Taconic, Cambrian, Silurian, Devonian, and other series up to the present period, or at least during a considerable portion of this time (for strata may have been deposited here during some of these periods and afterwards removed), we must assume that this region was above the sea level and was thus subjected to erosion. After the folding the surface was probably mountainous, and the amount of rock removed must have been enormously great; the number of hundreds of feet that the surface has thus been lowered can not be estimated. The effect of this long continued erosion was to gradually reduce the surface of the land to a lower level and finally when sufficient time had elapsed, an approximately flat surface not far above sea level would result. The probability of the production of such a flat or base-leveled area in Minnesota and Manitoba during Tertiary and early Quaternary times has been shown by Mr. Warren Upham,† and this cause will very conveniently explain the generally flat and plateau-like character of the Rainy Lake region. Since the production of this base level the hard Archean rocks have not been deeply eroded, and the surface consequently still retains approximately this base-leveled topography.

Glacial agencies have, since the base-leveling, removed any decayed rock or other material that may have remained on the rocky surface, and have produced the gently rounded and hummocky surface now existing. Since glacial time the Archean area has suffered practically no erosion, the lakes and streams following the depressions and irregularities which remained at the departure of the ice-sheet. The clayey plain to the west of Rainy lake also shows evidences of having been subjected to erosion for but a short period, and even during this time the erosion has not been extensive or violent.

---

* H. V. Winchell: Geol. and Nat. Hist. Surv. of Minn., 17th (1887) Ann. Rept., 1888. Amer. Geol., vol. 12, pp. 220-223, Oct., 1893.
J. E. Spurr: Geol. and Nat. Hist. Surv. of Minn., Bull. 10, pls. 10 and 11, 1894.

†Amer. Geol., vol. 14, pp. 235-246, Oct., 1894.

The surface is still monotonously flat except for the narrow, steep-sided, shallow trenches cut into it by the Rainy river and its tributaries; and only the largest of these streams have cut entirely through the blanket of clays down to the underlying rock, while none of them have excavated channels in the rock itself. This clay plain thus presents the peculiarities which are characteristic of a topographically young surface.

DESCRIPTION OF VEINS IN GENERAL AND OF INDIVIDUAL PROPERTIES.

At the time this examination was conducted but little more than a year had elapsed since the first shot was fired in a gold quartz vein on Rainy lake. Remote from railroads, with not even a wagon road at that time to connect it with the rest of Minnesota, this region must of necessity have a slower development than other new districts of equal natural resources but greater accessibility. Reached by a hundred or more miles of canoeing, Rainy lake had prior to 1894, been seen, aside from those who traveled the "Dawson route" in the "seventies," only by a few trappers, pine estimators, explorers and natives. The few farmers and traders who remained on Rainy river after this route across the country from Fort William to Fort Garry was abandoned—owing to the construction of the Canadian Pacific railway—rarely left their farms or trading posts to go to Rainy lake; and the few lumbermen engaged in their work around the lake were there only when the rocks were covered with snow. So it is little to be wondered at that the quartz veins remained undiscovered and undisturbed. Gold is usually found in placers and from them traced to the lodes whose rotting has produced the placers. But here there are no placers, and the veins are not rotted to any depth,—another reason why they might easily be overlooked or condemned as barren. But explorers for mineral deposits have sharp eyes. They examine everything that falls beneath their gaze. With pick and pan they pound up and wash every piece of rock that has a rusty stain, every fragment of quartz that comes into their hands. To them one species of rock is as good as another. In fact they frequently cannot tell the rocks apart or any of their names correctly. But an explorer's unaided eye can often detect at a glance a speck of gold that a mineralogist might

pass over with a magnifying glass. His scent is keen and his zeal unflagging. Thus it happens that he sometimes stumbles upon discoveries in unexpected places.

The recentness of gold discoveries at Rainy lake, and its remoteness from railroads has delayed development. It can hardly be said that there are any mines as yet in the entire district. The depth of the deepest shaft did not exceed 45 feet at the time of examining it, and there are no underground levels. But one 5-stamp mill is thus far set up in the region—that of the Little American company, and not more than 500 tons of ore have been milled. The result of operations here, however, has been sufficiently encouraging to induce several other companies to order mills, and it is expected that there will be half a dozen mills in operation before the end of 1895.

Throughout the region quartz veins are common and even abundant, but most of them are small and insignificant and contain no minerals of economic importance. These small veins, known as gash veins, cut the rocks in various directions as narrow ribbons which gradually taper to a point and disappear; they are thus of limited length and are at most only a few inches wide, the majority being less than one inch across. They are found in all the rock series of the region and are especially noticeable in some of the gneisses and granites. These small gash veins are not known to be of any value, and exploitation of them is useless.

The prospecting for gold is now being conducted in three different classes of deposits, if we include those of the Canadian side as well as those in Minnesota. These three classes are (1) segregated veins, (2) fissure veins, (3) fahlbands; the first two being properly called veins, the last being rather belts of the country rock charged with an unusual amount of metalliferous material.

I. SEGREGATED VEINS.

The veins on the south side of Rainy lake and hence all those in that portion of the gold district which lies in this state, are of the variety known as "segregated veins." They are conformable with the bedding or foliation of the schists, but their gangue, being chiefly quartz, differs entirely in mineralogical composition from the enclosing rocks. This class of veins may extend with unbroken continuity for a considerable distance through the country rock, or may form lens-shaped bodies of limited extent, occupying a more or less distinctly defined belt

of country. They vary in thickness from an inch to five or more feet, and may extend continuously for fifty or a hundred feet, or may pinch out in a shorter distance. When one of these quartz lenses is found, usually others exist close by in the direction of the strike; and, moreover, two or three of these lenses may be found side by side, or overlapping each other, being separated by only a few inches of the country rock. Thus there commonly exists a belt of rock, from one to ten or even more feet in width, in which quartz lenses are common; and in this belt the rock around the lenses is more or less completely impregnated with quartz. To this belt of quartzose rock, including the quartz lenses, the miners and explorers loosely apply the term *vein*. The "vein" may thus be several feet in width, but it is not composed wholly of vein material; in fact, it is seldom more than half quartz, and usually the quartz makes no more than one fourth of the total. The accompanying figure represents the surface exposure of one of these veins; it also represents fully as well a vertical cross section of the vein. The areas of undulatory lines indicate the country rock and the darker areas the quartz lenses, while the dotted area represents the belt of country rock which is more or less impregnated with quartz. The last two parts form the vein, using this term in its larger sense.

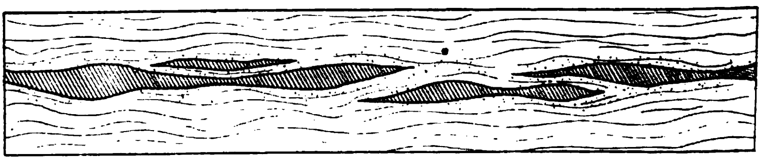


FIG. 2.—Generalized surface section of one of the segregated veins.

The minerals occurring in the veins are not many. The lenses are composed of pure white coarsely crystallized quartz; sometimes no other mineral is present. Usually, however, and always in the gold-bearing veins, there is some pyrite and a dark chloritic material which can generally be referred to fragments of the country rock. Pyrite is also frequently disseminated through the quartz-impregnated rock which surrounds the lenses. The gold occurs associated with the pyrite, but sometimes small flakes can be seen in the white quartz apparently entirely separated from the pyrite. Where the veins have weathered or decayed, particles of gold, the size of a pin's head or occasionally much larger, can be found on the surface of the

vein in cavities left by the decay of the pyrite. Most commonly no gold is visible to the unaided eye. The gold is confined principally to the quartz lenses, but also occurs in small amounts in the quartzose rock around the lenses.

These veins vary considerably in width and in the amount of quartz and the number of quartz lenses in them. A vein that is ten feet wide and half to two-thirds quartz in one spot may vary in the distance of a few rods to half that width and may contain not more than a fifth part quartz; or on account of the absence of the quartz lenses it may be almost unrecognizable. Further on it may widen out and contain a large number of the lenses. Variation in the amount of gold seems to be as common and as pronounced as variation in width or number of quartz lenses.

On account of the water covered areas and those covered by swamps or soil, no vein has been traced any great distance, but in all probability they will frequently be found to extend more or less brokenly for several miles. The vein of the Little American mine appears again on the island just to the west of the one on which this mine is situated; while to the east and in the direction of the strike apparently the same vein appears at several places:--on the south shore of Rainy lake in the S. W. ¼ of S. W. ¼ sec. 26, T. 71-22; in the S. E. ¼ of S. E. ¼ of the same section; and also on the island in the S. W. ¼ of S. W. ¼ sec. 25. Thus when a vein is known at one point it can confidently be searched for again in other exposuros along the strike, but nothing can be safely predicted as to its size and richness at other points. These facts can be determined only by exploitation and assays, but a vein which has a considerable width and richness at one point will more probably have the same characters at other points. In making these statements concerning the extent of certain veins over considerable distances reference is had only to the larger and more pronounced ones, *i. e.*, those which are several feet in width and which have a number of quartz lenses lying side by side or nearly so. Single lenses of quartz are not uncommonly found, but these are of only small size and others can not always be found by following along the strike of the first.

As has been already stated these veins run parallel to the strike of the cleavage of the country rock. They are thus narrow beds now standing in a nearly vertical position and extending indefinite distances. They occur in the rocks of both the Keewatin and Coutchiching. The veins found in the Coutchi-

ching rocks are almost entirely of pure quartz, containing very little other mineral matter. They are very poor, or entirely lacking in gold. None of the veins in this series of rocks have as yet proved of value. The veins in the Keewatin rocks are richer and are the only ones in which paying amounts of gold have been found on the Minnesota side of the lake. The best veins occur in the greenish schists of the Keewatin. As far as known the most promising belt of this rock is that which comes to the shore at the head of the bay in the N ½ of sec. 32, T. 71-22, and extends eastward from there, including the Little American island and those just to the west of it, a narrow strip along the south shore of the lake eastward from Rainy Lake City to the west line of St. Louis county, and the small islands just to the north of this shore. Another belt of this rock just touches the north side of Dryweed island and in it is the Lyle mine, near the center of the S. E. ¼ of sec. 23, T. 71-22.

A consideration of the manner in which these veins were probably formed may throw some light on their exact nature. The cleavage planes of the country rock, parallel to which lie the veins, while trending on the whole in one general direction, still vary to a certain extent in their directions in distances of a few inches or feet, *i. e.*, they are undulating. An attempt was made to indicate this fact in the cut (figure 2, page 74) representing a section of one of these veins; here the undulating lines represent the cleavage planes of the rock. This cleavage is seen to be undulating or wave-like in form in a vertical as well as in a horizontal section. The surface of one layer of the rock may be very roughly likened to the surface of a lake with a "choppy" sea; just fitting into this surface is another complementary one of the rock layer next adjacent. Along the veins there has been some slipping (or faulting) of the different layers on each other; that this is the case is indicated by the sheared and crushed condition of the rock and by the frequent slickensided surfaces. When this faulting occurred, especially where there was no great pressure normal to the fault plane, there would be formed certain irregularly lens-shaped cavities where the surface of one layer did not fit the surface of the next adjacent one. These lens-shaped cavities are now represented by the lenses of quartz. This faulting would not be confined to slipping between two layers alone, but would occur between several adjacent layers, so that the faulted area is not strictly a plane but a bed of several inches or feet in thickness. How great this faulting has been we do not know,

but that the area of weakness, in which were crushed rock and cavities, extends to a considerable depth seems quite certain. In this area of weakness solutions would easily travel and mineral matter would be deposited from them; thus would occur the impregnation of the crushed rock and the filling of the cavities. Under this view of the origin and nature of these veins it is seen that they lie along lines of faulting and that they could thus receive solutions emanating from great depths; thus these veins are in many features closely analogous to true fissure veins.

General considerations bearing upon the question of the source of the metalliferous constituents of these veins have already been given. In this connection, however, the views of Dr. A. C. Lawson upon this subject are pertinent and interesting, coming from one who has carefully studied the region under consideration. He says:*

The distribution of veins and metalliferous deposits in the Archæan has further an interesting bearing upon the question of the history of these rocks. The Laurentian rocks of the region are remarkably barren of metalliferous deposits. The Upper Archæan, particularly the Keewatin series which is largely composed of volcanic rocks, is rich in such deposits as native gold (with a little associated silver), iron ores, copper pyrites, iron pyrites, mispickel, galena and zinc blende. These minerals are abundant in the Keewatin series, though, of course, only occasionally found sufficiently concentrated to be of economic value.

There can be but little doubt that their occurrence in these rocks is intimately associated with the volcanic rocks, although the period of their formation is not necessarily that of the formation of the volcanic rocks themselves. Now, unless we regard the floor upon which the upper Archæan was deposited to have been the original crust of the earth, for which supposition we have no good evidence, we must assume that it was made up of ordinary strata, either volcanic or sedimentary, or composed of both. As such it is probable that it was traversed by veins, and that in the volcanic portions, if not elsewhere, these veins were metalliferous.

But in the Laurentian we do not find anything like the number of veins that are found in the Upper Archæan, and those that are occasionally observed are not metalliferous. The simplest explanation of this marked difference between the Upper and Lower Archæan, as regards veins and metalliferous deposits, appears to the writer to be precisely that which gives a satisfactory account of all the other features of the region, viz: that the Laurentian rocks have passed through a state of fusion, while the superincumbent Upper Archæan remained unfused. This fusion would cause the dissemination throughout the magma of whatever metalliferous deposits had been segregated in veins, so that they could not be detected by ordinary means. The veins which cut the Upper Archæan are probably, as before suggested, due to aqueous emanations from the Lower Archæan magma, the metals in the veins being probably derived from the

*Congrès géol. international. 4me Sess., 1888, p. 145.

volcanic rocks traversed by these emanations, so that the very causes which obliterated veins and metalliferous deposits in the lower portion of the Archæan may be said to have given rise to those in the Upper Archæan.

Little American mine.

This vein, the first to be discovered and developed, belongs to the class of segregated veins. Situated on a small island in the N. W. ¼ of sec. 33, T. 71-22, one hundred miles from any railroad, and developed in the face of all the obstacles to be met with in a new district, it has served to attract attention to this undeveloped portion of our state, and, whether it proves to be the most profitable mine in the region or not, it will in this way always be remembered as the most useful.

Geo. W. Davis discovered the vein while prospecting alone about the last of July, 1893. Reaching the island one evening about dark he had no opportunity to examine the quartz which he saw until the following morning when he "panned" it and obtained gold. Mr. Davis remained on the island and in the vicinity for nearly a month and then went only as far away as Fort Frances to renew his store of provisions. On his return, about the last of August, he brought back with him a man named Quirk and a blacksmith from the "Fort" and together they fired the first blast on the 29th day of August, 1893. Subsequently going to Duluth with samples of his ore and telling of his discovery, a company called the Bevier Mining and Milling Company was organized in January, 1894, with A. S. Chase, "Hutch" Bevier and "Jeff" Hildreth as incorporators. Having some trouble to secure title to the land it was purchased from the government by using the right of selection or "scrip" of the St. Paul, Minneapolis & Manitoba railway. Active operations were at once begun under the direction of Mr. Hildreth and a 5-stamp mill was set up on the mainland at Rainy Lake City, about one mile from the island, where the shaft was sunk. This mill began stamping on July 16, 1894, and continued with some interruption until Sept. 24 of the same year, when, having used all the ore in stock and finding the cost of the operation too great, it was shut down. Shortly afterwards the operation of the mine and mill passed into other hands and plans were laid for work on a more systematic basis. A casual inspection of the mine will reveal a woeful lack of business ability in the arrangement and execution of the operations of mining and milling. The expenses must have been at least double what they should have been, even with so many difficulties to overcome. The hole in the ground, called by courtesy

FIG. 1. KOOCHICHING FALLS; MIDDLE SHOOT, LOOKING FROM THE MINNESOTA SIDE TOWARD FT. FRANCES. JUNE, 1894.

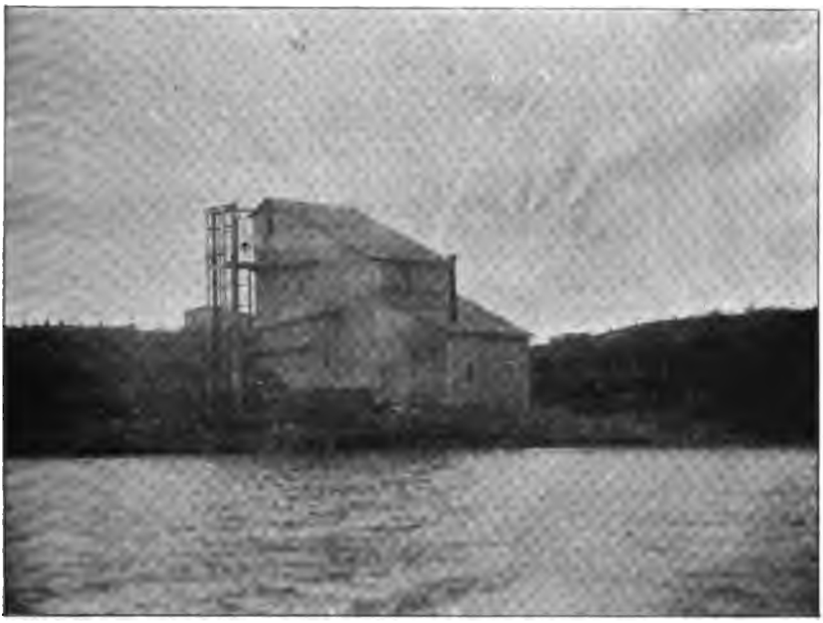


FIG. 2. THE FIRST STAMP MILL AT RAINY LAKE. ERECTED FOR THE LITTLE AMERICAN MINE.

a shaft, was about 10'x40'x44' and was as ragged a cavern as can be found in the state. With no timbering, no pumps, nothing but a hand windlass for hoisting ore, rock and water, and the mill a mile away, it is a good example of the folly of robbing a mine in order to provide ore for present purposes without proper development for future mining. Every item of expense must necessarily have been abnormally large by such poor management as is here displayed.

As to the operation of the mill the following quotation from a letter received from Mr. A. S. Chase, one of the directors of the Bevier Mining Company, contains considerable reliable information:

From the best information I have the mill ran in all fifty-two days. The nearest estimate as to quantity of ore crushed is 500 tons. We have no record of each clean up but the actual shipments of bullion were: August 10th, $362.30; August 20th, $1,958.85; September 18th, $2,481.76; October 18th, $732.42; total, $5,535.33. The cost as near as we can tell, was about $7.00 per ton for mining and milling. With proper management it can doubtless be mined and milled for $3.00 per ton. We have but five stamps and of course the cost of milling would necessarily be large, but there are other reasons for the great cost of producing this bullion which can be easily overcome. The mill produced all the way from 8 to 27 ounces of bullion per day, showing very clearly that quantities of rock were crushed which, with proper sorting, would not have been used, especially with this little mill. It is certain that there was no attempt at deception and I am fully convinced that gold in largely paying quantities exists in the Rainy Lake region.

The vein is about ten feet in width and dips south about 80°. Its strike is N. 80° E, and it is believed to run across the next island west of the Little American. The ore is gray quartz with streaks and masses of the schist which constitutes the country rock enclosed in it. It contains a rather small amount of pyrites and some visible gold. Less than five per cent., and perhaps less than three per cent., of the ore goes into the concentrates which have an assay value of about $12.50 per ton. Samples of the ore taken from the vein at the depth of ten feet and from the top of the stock pile where the ore from the bottom of the pit was supposed to lie, assayed $11.51 ($11.39 gold and $ .12 silver), and $3.37 ($3.31 gold and $ .06 silver) respectively.

Big American mine.

This is the homestead of George Davis, the discoverer of gold at Rainy lake. The property constitutes the southwest corner of Dryweed island. A pit five feet square and five feet deep has been dug in the usual siliceous sericitic schist of the

island. In the pit are three quartz lenses, none of them more than a foot in width. The rock at the pit is more schistose and greener in color than the adjoining rock. The strike is N. 70° E. (mag.), and the dip is 90°. Exposures near by show other quartz lenses along the strike a few yards from the pit, but not enough work has been done here to show the width and probable extent of the vein.

Other prospects.

In the vicinity of Rainy Lake City are several places where some work has been done, but the veins are small or the exploitation has not gone far enough to show clearly their extent and value. Some of these prospects will be mentioned below.

On the eastern end of the island in the S. W. ¼ S. W. ¼ sec. 25, T. 71-22, a shaft has been sunk. It was reported to be down to a depth of twenty-eight feet, but in October the work had been abandoned and the shaft was partially filled with water; a short drift has been run out towards the south. The vein here, *i e.*, the belt of siliceous rock in which the quartz lenses occur, is about three feet wide as exposed at the surface.

The blunt point of land in the S. W. ¼ S. W. ¼ sec. 26, T. 71-22, is crossed by another vein, which has been uncovered at several places. In some places there is a width of nearly six feet of almost pure white quartz. This vein is probably a continuation of the one just mentioned on the island.

In the S. E. ¼ of S. E. ¼ sec. 23, T. 71-22, is a small island on which is what is known as the "Old Soldier mine". The island is made of mica schist in which are small veins of quartz and some beds or dikes of gneiss or foliated granite. This granitic rock varies in color, being light or dark according to the amount of biotite or hornblende it contains. A considerable amount of pyrite is disseminated through this rock.

The large island in the N. W. ¼ of sec. 26, T. 71-23, known as Kingston island, has a few small veins running across it. Some work is now being done upon these, but at the time of our visit it had not progressed far.

The vein of the Little American mine is seen again on the island nearest west of the Little American island, and the company has commenced operations here and are uncovering the vein and have started a drift along side of it.

It was formerly supposed that segregated veins are not so persistent as fissure veins, and that they are not so likely to be productive in depth. This view does not appear to have a

basis in fact, however, since "recent mining operations have materially modified the received views respecting the value and persistency of the so-called segregated veins. Many of them are of great thickness and extent, and, after having been worked to very considerable depths, have been there found as productive as they were nearer the surface. The character of the veinstone of such deposits frequently appears to in no way vary from that of true fissure veins, from which they often differ in no respect except that their course is often parallel to that of the strata between which they lie." (Phillips, Ore Deposits, p. 91).

II. FISSURE VEINS.

True or fissure veins have already been briefly described, and the prevalent theory of their origin outlined, Their distinguishing feature is their entire independence of the strike or foliation of the enclosing rocks. Indeed, because of the wavy line of strike of the crystalline and semi-crystalline rocks, a fissure vein almost always cuts across the strike in some portion of its course. The walls of fissure veins have usually a more direct and even course than those of other veins, and are smoothed or "slickensided" in a similar manner.

The veins in the vicinity of Rainy lake which present the characteristics of fissure veins are those in the vicinity of Shoal and Bad Vermilion lakes, east of Seine bay at the east end of Rainy lake. Occurring for the most part in a granitic rock, they strike north and south or northwest and southeast,—almost at right angles with the series of segregated veins. The quartz is somewhat different in appearance, perhaps due largely to the fact that it is richly charged with the sulphides of iron, copper, lead, zinc and silver, and near the surface with the oxidized alteration products of these minerals. The first of these veins to be brought to public notice as containing gold is on location "A L 75" and is known as

Wiegand's location.

Thomas Wiegand and Alex Lockhart discovered auriferous quartz veins on this and adjoining locations in September, 1893. The veins strike north-south, or northwest-southeast, and vary in width on the surface from six inches to six feet. The ore is charged with zinc blende, galena, pyrite and free gold and is somewhat stained by iron rust near the surface. There is dis-

tinct evidence of crustification in some of the veins, while in others the ore is more homogeneous in texture and appearance. The walls are well defined and finely slickensided. The country rock immediately surrounding the veins is mentioned elsewhere (p. 58), and is not inaptly called "bastard granite" by some of the explorers of the region. This rock has often a foliation which corresponds in general with the strike of the schistose rocks which lie south of Shoal lake. The trend of the veins is across the prevalent foliation of the granite, and their length is sometimes seen to be at least half a mile, as revealed by the outcrops. In connection with Col. S. W. Ray of Port Arthur, Ont., Mr. Wiegand has done considerable exploring on these locations in the way of uncovering the veins and sinking test pits.

Pit No. 1 was 12 feet deep on the lode, showing the vein to increase in width from about 6 inches at the surface to 20 or 24 inches at the bottom, with a vertical dip. Near the top of the ground the vein is banded pink, red and white; but the quartz is all light colored at the depth of 12 feet, and appears to be nearly equally charged with "sulphurets" throughout. Where stringers of quartz join the vein from the walls considerable free gold is said to have been noticed. Just west of this pit, and about 75 feet from it, a parallel vein three feet in width is seen to outcrop. The latter has not been prospected.

Sample from the stockpile at No. 1 pit assayed \$6.83 in gold and \$ .15 silver, a total of \$6.98 per ton.

Pit No. 2 is on location "A L 94." Its depth is 12 feet and it is sunk on two parallel veins separated quite sharply by a band of granite about two feet in thickness at the surface, and as far as shown in the test pit, the dip is about vertical and the strike north and south. Bunches of pyrites having a thickness of several inches are numerous in the eastern vein. Near the surface these were said to have been much rotted and held together by threads of gold. Considerable gold was obtained upon washing this pyrite in a pan, after crushing it finely in a mortar. A sample from the pile of quartz thrown out of the pit was assayed with the following result:*

Gold	2.32 oz. per ton, worth	....	\$48.02
Silver	.64 " "	....	.40
Total value per ton of ore		....	\$48.42

* The assays reported here were made by F. F. Sharpless in the laboratory of Sharpless & Winchell, Minneapolis.

Pit No. 3 is on location "A L 75," and at the time of examination was 19 feet deep. The vein is similar to those already described on these locations, striking north-south and having a width of one foot to three feet and a half, and growing wider as depth is attained. The dip is 80°. Samples taken from the stockpile and vein here gave the following assays:

Dump sample:

Gold, .35 oz. per ton, worth	$7.25
Silver, 2.46 oz. per ton, worth	1.55
Total value per ton	$8.80

Surface of vein:

Gold, 3.23 oz. per ton, worth	$66.86
Silver, .47 oz. per ton, worth	.30
Total value per ton	$67.16

The walls of these veins are smooth and sharply defined, being usually separated from the vein matter by a thin sheet of soft material, supposed to be the product of pressure, shearing and chemical alteration. Some of these veins can be traced for a mile across the country, maintaining their width and course quite persistently. The mineral content of the different veins varies considerably. Thus Vein No. 3 on Wiegand's location is more heavily charged with blende, pyrite, galena and chalcopyrite than Veins No. 1 and No. 2, but is no more richly "mineralized" than some veins seen elsewhere in this same immediate vicinity.

The Lucky Coon.

Hillyer's location. as it was first known, or The Lucky Coon, as it is now christened, is location "655 P" consisting of about 170 acres. It is situated, as shown on the map, north of the eastern end of Shoal lake, and east of Bad Vermilion. The country rock here is quite similiar to that at Wiegand's; but the granite is coarser and more massive, and has pink feldspar crystals developed in it at a short distance from the veins. At the time of examination two nearly parallel veins about 150 feet apart were being developed by shafts. This property is operated by Hugh Steele, of Duluth, W. G. Miller, of Minneapolis, Geo. Hillyer, of West Superior, and Carrol Carson, of Biwabik, Minn. The work was being done under the direction of Mr. Hillyer. Other parties who own an interest in it are Wm. Campbell and Messrs. Mosher and A. L. Robinson. The Seine River Mining company, of West Superior, Wis., is

organized to work this mine, and a stamp mill is to be ordered at once. The strike of the veins is about E. 25° S. The more northerly one (No. 1) dips N. 25° E. 80°, while the more southerly one (No. 2) dips S 25° W, 80°, in other words the two veins are each within 10° degrees of verticality and dip away from each other so far as revealed by test-pitting. It is to be expected that the dip of one or the other vein will change so as to bring them both to a conformable dip in the same direction.

Pit No. 1, on Vein No. 1, at the time of our visit was about 10 feet deep, and its dimensions about 6x10. The vein has a width of about 6 feet and has good walls. It is banded or "crustified" and contains considerable pyrite, chalcopyrite, blende and a dark mineral resembling argentite. This vein has been traced for more than half a mile by surface outcroppings. The best ore is said to come from near the foot wall. A sample of ore taken from the bottom of the pit assayed $2.07 in gold, and showed no silver.

Pit No. 2 is on Vein No. 2, which has a width of 5 feet where exposed. It was very heavily mineralized from the surface to the bottom of the pit which was only 9 feet deep, and showed considerable gold in a decayed and oxidized state that was seen in the middle of the vein. The walls are smooth and slickensided and indicate a good depth to the vein. It contains the same sulphides noticed in Vein No. 1, with the addition of galena, and where these minerals have been removed by oxidation there is often a beautiful display of flecks and small nuggets of gold. Sample from all over the pile of ore thrown out of the pit gave just the same results as the sample from No. 1 pit. Ore taken from a heavily mineralized portion of the vein yielded an assay value of $43.26 gold per ton.

Other prospects near Shoal lake.

The Mosher properties are "A L 110," "A L 111" and "A L 112," and are in the same rock as Wiegand's and Hillyer's locations. Some prospecting has been done here on a vein that has a width of six feet and strikes northwest and southeast. Flecks of gold are visible in the vein matter, and the ore is quite similar in many respects to that of the Lucky Coon.

It is evident from a description of these veins that a larger percentage of the ore from those fissure veins near Shoal lake will be of the kind called refractory than is the case with the ore from the segregated veins contained in the Keewatin schists. What percentage this will be cannot yet be told. Some of the gold is contained in the quartz without association

with the sulphurets, but much of it is so intimately mingled with them as to require treatment as refractory ores. It is also to be expected that the percentage of free-milling ore will decrease with depth. Certainly so far as the amount of free-milling ore is dependent upon oxidation of the sulphides there will be a rapid increase in the amount of refractory ore below the surface, for oxidation has extended but a few feet into the veins since the glacial period. It is quite possible, however, that a considerable proportion of the gold exists in the ore in a condition to be removed by milling and amalgamation, independently of any oxidation of the sulphurets. In that case there will not be so great a change in the ore as the mines grow deeper.

The veins in this vicinity being very numerous, nearly all of the land is already surveyed into mining locations and sold under the mining laws of Ontario. Lying a little outside of the district which properly comes under the jurisdiction of the Minnesota geological survey, the Seine river and Shoal lake region was only examined sufficiently to obtain an idea of its general worth, and many prospect holes and veins were not seen. Enough was seen, however, of individual properties, and of the geology of the district to create the impression that this is destined to be the richest area thus far prospected around Rainy lake. The reasons for this belief may be briefly stated. The veins are fissure veins and cross the strike of the rocks nearly at right angles. The ore is well charged with heavy sulphides, and the gangue is considerably stained and colored with them. The walls of the veins indicate that they will extend indefinitely downward, and explorations have shown their length to be considerable. The rock which contains the veins bears evidence of having undergone great pressure, shearing and chemical metasomatosis, and corresponds in age and mineralogical composition to the usual associates of auriferous veins.

But perhaps the most favorable feature of the veins of this particular portion of the Rainy Lake district is their intimate relation with the areas of eruptive rock called "gabbro" on the north and of greenstone on the south. This gabbro occupies an area of several square miles around Bad Vermilion lake, and there can be but little doubt that it has been of great importance in the formation and enriching of the veins in its neighborhood. It is not clearly proven that the veins date from the advent of the gabbro; but the fact that the gabbro seems to be

later than the peculiar granite area lying between Shoal and Bad Vermilion lakes, and the further fact that the veins are quite different in strike from the other veins around Rainy lake, and appear to radiate from the gabbro area, as a center, is strongly indicative that the formation of the fissures was due to the irruption of the gabbro. As already stated, the proximity of eruptive rocks is almost universally believed to have exerted a beneficial influence on the richness of metalliferous veins, and it will be strange if it does not prove so in this instance.

III. FAHLBANDS.

Fahlbands are belts of rock, often of considerable width and extent, impregnated with sulphides of iron, copper and zinc, and sometimes, also, of lead, cobalt and silver. There are usually several of these belts having a considerable degree of parallelism with one another, and sometimes traceable upon their line of strike, for several miles. The amount of ore contained in such belts may be quite considerable, but it is only in a few localities found to be sufficiently concentrated to render its exploitation profitable. Fahlbands are usually found in regions of gneiss, mica and hornblende schists, talc schist or chlorite schist. Veins of quartz may be present in these fahl bands, running parallel with or intersecting them at various angles, but they are sometimes wanting entirely. There is usually a gradual transition from the metalliferous rock of the fahlband into the barren rock on either side, with which the fahlbands are usually conformable. When intersected by dikes of eruptive rock or veins of quartz there is frequently a considerable degree of enrichment at the planes of intersection. There are several points around Rainy lake where prospecting is in operation in fahlbands. Some of these are not worthy of mention. The best example of this class of deposit is the Lyle mine.

Lyle mine.

This is situated on a narrow point which runs out from Dryweed island near the center of the S. E. ¼ of sec. 23, T. 71-22, two and one-half miles northeast of Rainy Lake City. This property was located in the winter of 1893-'94 by William and Edwin Ward of Duluth. Work was begun on the shaft, which is eight feet square, on September 8th, 1894, and, at the time of our visit, a month later, it had reached a depth of twenty-two feet. The shaft is down in a peculiar kind of siliceous rock which consists of narrow bands of (1) finely divided quartz, (2)

a dark greenish material, perhaps largely chlorite, and (3) bands of 1 and 2 combined. This rock constitutes a band about twelve feet wide. Throughout it are numerous quartz stringers or lenses of all sizes from those a fraction of an inch in thickness to one which, where exposed, is two and a half feet across. The quartz lenses and the belt of rock in which they occur contain a considerable amount of pyrite, more than is common in the veins about Rainy Lake City. Masses of coarsely crystallized siderite are found in some of the quartz lenses. This belt of siliceous rock, including the lenses, is probably two-thirds or more quartz, and it will be necessary to mine and stamp the whole rock as ore, as it is impracticable to separate the quartz lenses. Moreover, the siliceous rock, as stated above, contains considerable pyrite, and possibly some gold.

The country rock at this place is composed of chloritic and sericitic schists and a green schist in which are many small spots of siderite. The strike is N. 75° E. (mag.) and the dip 75° to 80° north of this line. Just to the south of the little point, on which the shaft is situated, on the main land of Dryweed island the rock is the usual sericitic schist which has been mentioned before (page 66) as forming grindstone and Dryweed islands. Here a few quartz lenses occur, but they have not yet been uncovered so as to show their true size and extent.

The surface of the vein at the shaft is rusted and more or less decayed, but this condition does not extend downward more than four to six inches, except along cracks.

TREATMENT OF RAINY LAKE ORES.

The development of the Rainy Lake region has not been sufficient to furnish data on which to base a statement as to the best method of treatment for its ores. Conservative and business-like methods and principles would lead investors to be absolutely certain that ore existed in quantity sufficient to supply a stamp mill for a few years, and that it was of such a characacter as to be best treated in a particular kind of stamp mill before risking their money in the purchase of one. And in order to gain such information it would be necessary to sink shafts numerous enough and deep enough to prove the quantity and quality of the ore. The mere fact that four or five stamp mills have been built for use in this region where there is not as yet a shaft or a drill-hole 75 feet deep, is in itself sufficient proof that the mines are being developed by parties of little or no experience in the mining business. There can be only one result

of such hasty, ill-advised methods of procedure. Some, if not all of the companies will soon find themselves financially embarassed. The money which should have been spent in mine development will have been spent for machinery. When the stamp mills are on the ground and ready for operation there will be no ore to run them for any length of time, and not enough development in the mines to enable them to produce what the mills require. Thus the mill must be shut down and the public will say it was because there was no gold in the ore. The stockholders will be discouraged and the treasury of the company will be depleted without means of replenishing it. In other cases the free milling ore will so rapidly pass into refractory ore as the depth of the mine increases, that the mill which was built to treat the surface oxidized ores is unable to extract the gold from these more refractory ores, and must be discarded,—a dead loss to the company—and a new plant purchased. All of these things will exert a damaging influence on the reputation of the district as a whole, and should be avoided if possible. In a new district double precautions should be taken to insure against mistakes. Two or three shafts each 100 feet deep should be sunk and connected with levels on every property before a stamp mill or other plant is purchased. Then, with the mine opened up, and enough ore in stock to run the mill for six months, the mine will have a bona fide value. No difficulty will be experienced in raising money to buy the machinery needed. No hesitation will be felt as to what process to use. No trouble will be had in keeping the mill supplied with ore. The experience of the Lake of the Woods district should not be repeated at Rainy lake, but that is just what will happen if matters proceed as they are begun. Too great stress cannot be laid on this point. The old adage that "haste makes waste" is nowhere better exemplified than in matters of this sort. For the good of the pioneers, who deserve to succeed because of their confidence in the new region, and their efforts to develop it, no less than for the good of the district, we would urge upon the owners of prospects to "go slow" and develop their properties before ordering expensive concentrating and metallurgical plants.

As already stated, the ore which occurs within fifty feet of the surface of the ground at Rainy lake is free-milling, and the proportion of concentrates will not exceed 10 per cent. How much this percentage will be increased in depth is uncertain, but that there will be an increase is to be expected. With

five or ten per cent. of the ore going into the concentrates there will be required facilities for treating these refractory sulphides on the spot. The expense of transportation to a smelter and the high smelter charges make shipping out of the question. Some method of treating the sulphurets cheaply at the mine or on the lake must be introduced.

In this connection the description of barrel-chlorination by the Thies process as conducted at the Haile mine, Lancester county, South Carolina, is of interest.* Working on a large scale, ore which assays $4.50 per ton on an average and contains 10 per cent of concentrates is treated at a profit by this process. The value of the roasted concentrates amounts to $30.00 per ton and the cost of roasting and chlorination is said to be $4.62 for 1⅛ tons raw pyrites. After thoroughly roasting the sulphurets the roasted material is placed in lead-lined iron cylinders 60''x42'' which rotate on their major axes 20 times per minute. Chlorine gas generated in these barrels dissolves the gold in from 4 to 8 hours, and it is then precipitated by ferrous sulphate. With an abundance of cheap fuel and water power this process might be practicably introduced in the Rainy Lake region, and operated in conjunction with stamp mills and amalgamation.

SOME OTHER GOLD MINES.

In reports of discoveries of gold ore in new regions we frequently read references to the wonderful results achieved in treating low grade ores elsewhere and the large dividends that some celebrated mines are regularly paying. Comparisons are drawn between the small yield of gold per ton in these large dividend-paying properties and the reported average of the ore in the newly discovered field, and it is usually the conclusion drawn from such comparison that if one mine can make a regular profit out of three or four dollar ore, any other mine ought to make proportionately greater profit out of eight or ten dollar ore. Such, however, is not the case, and it is for the sake of guarding against such misleading comparisons that the following brief description of some of these famous mines is introduced here. Among the mines thus most frequently referred to in this country are the Homestake, the Alaska-Treadwell and the Comstock.

---

* Trans. Am. Inst. Min. Eng., vol. xix, p. 607.

Homestake mine.

The Homestake mine is located in the Black Hills, near Deadwood, South Dakota. The ore is not in a vein, but rather in a "belt" or zone of slates or schists containing many lenses and shoots of ore, consisting of quartz impregnated with more or less pyrite. This "belt" is about 2,000 feet in thickness and is bounded on the east and west by quartzytes. The age of these rocks is Archean, corresponding to those in the Rainy Lake region; and the gold contained in them was partially introduced prior to the Potsdam epoch and partially at some subsequent period. The rock seems to have been enriched by the influence of certain intrusions of porphyry, and is more productive and of a less refractory nature near these intrusions. The ore is what is called "free-milling," but still contains several per cent. of pyrites which pass into the concentrates and are treated by some metallurgical process for the gold they contain.

At the several properties located along this "belt" there are various methods of mining in vogue. Surface ores were taken out in large open cuts, but at present most of the mining is underground and conducted on a scale of great magnitude. Immense quantities of ore are mined and put through the stamps, as may be seen by an inspection of the annual reports of the operating companies. Several hundred stamps are kept at work, pounding out from two to four tons per stamp per diem. The average yield of gold per ton varies from $2 to $4, averaging about $3.87 in the Homestake mine, and $2.42 in the Deadwood-Terra and other mines where porphyry intrusions do not occur. In 1888 the cost of mining at the Homestake was $1.68 per ton, and the cost of milling was $0.83, a total of $2.51. The yield for the same year was $3.71 per ton, leaving a net profit of $1.20. (A. I. M. E., xvii, 577.) As there were mined nearly a quarter of a million tons of ore, the total profit was a handsome one. The dividends paid by the Homestake company from 1884 to 1892, inclusive, amount to $4,943,750.

Alaska-Treadwell.

Although in operation but a few years the Alaska-Treadwell mine has paid its owners dividends amounting to $2,225,000 up to 1894. This mine is situated on the eastern side of Douglas island, on the coast of Alaska. The ore deposit consists of a mass of quartz and white feldspar of medium grain and pale

gray color, containing a small amount of calcite and impregnated throughout with small crystals of iron pyrites. The thickness of the ore body is from 400 to 500 feet, and it is bounded on the northeast and southwest by dark colored argillytes supposedly of Triassic age. Mr. G. M. Dawson suggests* that "this ore body is the upper portion or feather edge of a granitic intrusion, probably contemporaneous and connected with the characteristic granites of the neighboring coast ranges, but which, owing to peculiar conditions has become decomposed and silicified by solfataric or hydrothermal action, to which the concentration of gold in it, and the deposition of pyrites are also due."

Since 1888 the mine has operated 240 stamps and 96 concentrators which have milled and concentrated 500–700 tons of ore each 24 hours. Although largely a free milling proposition, there are several per cent. of concentrates which are roasted and chlorinated.

The cost of chlorination in 1890 and 1891 amounted to 22 and 19 cents respectively per ton of ore milled. The cost per ton of concentrates treated for these years was $9.02 and $7.61 respectively.

The average total cost of mining, crushing, amalgamating, retorting, etc., in 1892 was about $1.50 per ton, on an average product of 16,000 tons of this ore per month The assay value of the ore is only about $3.75 per ton and yet it is mined and treated so economically as to have a net profit of nearly $2.00 per ton.

Comstock lode.

Differing materially in the character of ore deposit, enclosing rocks, situation and product, from the two mines just mentioned is the Comstock lode, the largest producer the world has yet seen. The contrast between it and the Homestake mine is illustrative of the very point which we seek to emphasize, viz., that location, nature of the ore and cost of treatment have more to do with the question of profit and loss than the assay value of the ore itself.

The Comstock lode consists of wide, gently dipping masses of crushed and decomposed country rock cemented together and filled up by saccharoidal granular quartz and some calcite in all of which the ore is very finely disseminated. Enclosed

* Am. Geol. 1889. vol. 4, p. 84.

almost wholly in eruptive rocks, basalt, augite andesyte, quartz-porphyries, metamorphosed diorytes, phorphyritic diorytes and granites, it was not to be wondered at that hot waters were encountered at great depths in the mine, or that these hot solutions had effected the deposition of such a marvelous store of wealth. The foot-wall is dioryte from Gold Hill to Virginia City, metamorphic slates south of Gold Hill, and in one place for a short distance a diabase dike. The hanging-wall is usually hornblende andesyte in the upper region and diabase in the lower levels.

The ores are silver ores, stephanite, polybasite, argentite and some galena and zinc blende. The bullion contains about 43 per cênt. of its value (6 to 7 per cent. of its weight) in gold, and 57 per cent. in silver.

The product of the mines located on the Comstock lode up to Jan. 1st, 1881, was, in round numbers, 7,000,000 tons of ore which yielded bullion valued at $306,000,000. The average value of the ore was $43.86 per ton inclusive of the amount lost in tailings. The dividends and profits up to the same date amounted to $118,000,000 which was reduced by assessments of $62,000,000 to a net profit of $56,000,000, showing that the cost of operation amounted to $35.71 per ton of ore produced.

These few facts show without any need of emphasis or comment, how widely different are the costs of mining operations under different conditions. Each mining district and each property in the district must be considered by itself and developed in the light of the conditions which surround it independently of what any other mine has accomplished or expects to accomplish. It is quite evident from the foregoing brief outline of facts that because the Homestake and Alaska-Treadwell mines pay dividends on four dollar ore is no reason why mines on Rainy lake can do the same; nor, on the other hand, that because it cost $35 a ton to mine and treat the ore of the Comstock lode it will cost the same in Minnesota. The fact to be emphasized is that under suitable conditions ore deposits can be profitably exploited even though the value of their contents varies from $35 down to $4 or less per ton. The next thing is to determine in each case whether the ore body is present or not, and under what conditions, and with what environments.

OTHER RESOURCES AND ROUTES OF TRAVEL TO RAINY LAKE.

I. OTHER RESOURCES.

This report is devoted primarily to a discussion of the gold-bearing rocks of the Rainy Lake region, but it will not be out of place to call attention to other natural resources as these must play an important part in the development of any mining district. Moreover, the presence in the vicinity of Rainy lake of an abundance of natural resources, other than the gold, is destined to aid very materially in the rapidity of settlement and development of the northern parts of Itasca and St. Louis counties.

Useful mineral substances.

In the large pegmatyte veins or dikes, which occur especially in the mica schists along the south shore of the eastern arm of Rainy lake and on the shores of Kabetogama lake, are plates of mica (muscovite) two or three inches in diameter. As yet no mica has been found in sufficient quantity or in large enough plates to be economically useful, but more careful exploration of these pegmatyte veins may be rewarded by the discovery of larger masses of this mineral.

Other minerals, such as iron pyrites, sphalerite (zinc blende) galena and copper pyrites, occur in the Rainy Lake region, especially in the quartz veins, but it is hardly probable that large amounts of any of these will be found.

The Keewatin rocks of this district are of the same geological age and of the same general character as the rocks in which are the rich iron deposits of the Vermilion range and some parts of the south shore of lake Superior. Deposits of iron ore have already been reported from the Seine River country, but as yet no careful exploration for iron ore has been attempted. We wish to call special attention to the probability of the existence of large masses of iron ore in the Rainy Lake region, and we feel that exploration in this line is more likely to result in the discovery of mineral wealth than exploration for any other mineral except gold. The rocks marked Keewatin on the map (plate I) are the ones in which exploration for iron ore should be carried on.

Many of the granites and syenites, and some of the other rocks, will make excellent building stones. Good material for grindstones, whetstones and hones, and probably also for

roofing slates, exist in the Keewatin rocks. The numerous limestone fragments found in the clays along the banks of the Rainy river have sometimes been burned for lime by the settlers. The clays to the west of Rainy lake contain beds which will evidently make good bricks, and some of the beds will probably be found to possess the characteristics necessary for some kinds of pottery.

Coal has been reported a number of times from the banks of the Big Fork and Little Fork rivers, which are in Itasca county and southwest of Rainy lake. This coal occurs in the form of lignite in the Cretaceous shales, which are known to outcrop in places along these rivers, and it is probable that rocks of this age exist, although usually buried under a considerable thickness of glacial drift, in most of Itasca county and the counties to the west. On account of the discovery and recent development of lignite beds in the vicinity of Redwood Falls, it is thought best to call attention to the possibility of the existence of similar beds in the region to the southwest of Rainy lake. This lignite in Minnesota does not seem destined to be of any great value, but possibly some of it may prove of local importance. In this connection we quote the statements made in reference to coal in Minnesota by the senior author of this report some two years since:

The opinion of the state geologist and the writer has been frequently expressed that the only coal of any sort in the northern part of the state is in thin seams of brown coal, occurring in Cretaceous shales, which were found in patches on the Little Fork river by the writer in 1887. This coal is not of good quality and the discovery of large amounts in thick beds would not be of such great importance as the newspapers would have us believe.

At the same time, lignite is used to a considerable extent in treeless regions as fuel for ordinary heating and cooking purposes. In Texas and Dakota such coal is mined in considerable quantities. Grates of a peculiar pattern are devised in which to burn this coal and it plays quite an important part in the domestic economy of those regions. It is used in the form of briquettes in Germany. These briquettes are made by drying the brown coal until the water it contains is nearly all driven off and then subjecting the mass to a pressure of fifteen hundred to two thousand atmospheres. The resulting briquette is elliptical in form, about six inches long and one inch thick. It is so hard that it will not absorb water even though laid in water for some time. The coal is too fine-grained and not compact enough to use in blast furnace practice. If this brown coal should be found dehydrated and consolidated by heat or pressure consequent on eruptions or excessive faulting in the rocks, it would have a much greater value. It is not impossible that such deposits may be found in some of the large areas northwest of Duluth as yet but little explored by the geological survey. It is quite desirable that some further

examination be made of this region in connection with more thorough and careful mapping of the rocks of the Mesabi range. The value of good coal d posits cannot be overestimated, and if we have such in Minnesota the sooner we know it the better.*

Timber.

The usual white and Norway pines are found throughout this entire region, but not always of sufficient size to pay for cutting. Yet, there are many places along the shores of Rainy lake and the adjoining bodies of water where there are groves of good sized pines; and many scattered areas of timber exist in the vicinity of the Big Fork and Little Fork rivers. Some of the pine has already been cut and taken to Rat Portage, but much remains to be cut as soon as the demand for lumber in this district increases. A saw mill was in operation near Rainy Lake City during the last summer and two or three others on Rainy river.

In hardwood timber the white birch, which occurs throughout the region and which often reaches a size suitable for lumber, may be mentioned; oak and elm of good size occur in the flat clayey district just to the west of Rainy lake.

The numerous swampy tracts of this part of the state are often covered by a dense growth of excellent spruce timber. This is used in large amounts in the manufacture of pulp and paper, and, as the more southern regions are being rapidly devastated of their timber, the spruce of northern Minnesota will soon become exceedingly valuable; growing as it does in the lower and damper grounds it is not so subject to destruction by forest fires as the pine.

Agriculture.

The plain of clays which extends westward and southward from Rainy lake is destined to support a large farming population. As already mentioned these clays were deposited in the glacial lake Agassiz and are thus of similar origin to the subsoil of large parts of the Red River valley. Above this subsoil is a considerable thickness of black loam. This land naturally supports a luxuriant growth of vegetation, and, where it has been cleared and cultivated, as in many places along the Canadian shore of the Rainy river, it has been found to yield large crops. Most all of the usual produce, excepting yellow dent corn, have been successfully grown in this district; and especially large returns have been made in oats, wheat,

* Geol. and Nat. Hist. Survey of Minn., 20th Ann. Rept., pp. 179-180, 1893.

potatoes, cabbages, turnips and hay. There are large tracts of land south of the Rainy river, which are as yet unsettled and which are unexcelled for agricultural purposes by other land in the state. As is usual in a new mining country the farming interests are neglected at first, but in the Rainy Lake district there is no reason why this should continue so, as the conditions for making farming a profitable business are here so favorable.

The following quotation from Dr. A. C. Lawson's report on the geology of the Rainy Lake region* is strong testimony as to the adaptability of the soil and climate of the region for the support of a dense population:

Agriculture is perhaps the most promising of the economic prospects of the region. Rainy river from its source at Coutchiching to Hungry Hall, flows for eighty miles through a rich alluvial plain, which, so far as can be judged from the banks of the river, is eminently adapted to support a large agricultural population. Travelers and explorers vie with one another in praising the beauties of the river and its capabilities for settlement. Mr. S. J. Dawson in his "Report on the exploration of the country between lake Superior and the Red river settlement" says of it, "The distance from Rainy lake to the Lake of the Woods, following the windings of the stream, is about eighty miles, and throughout the whole of this extent the land fronting on the river is fit for settlement without, I may say, a single break; indeed, I have never seen anything to equal it in my experience, except at Swan river and on the Assiniboine." * * * * Prof. H. Y. Hind in his account of the country examined by the same expedition says: "No part of the country through which we have passed from lake Superior northwards can bear comparison with the rich banks of the Rainy river thus far. The river has preserved a very uniform breadth, varying only from about 200 to 300 yards. The soil is a sandy loam at the surface, much mixed with vegetable matter. Occasionally, where the bank has recently fallen away, the clay is seen stratified in layers of about two inches in thickness, following in all respects the contour of what seems to be unstratified drift clay below. Basswood is not uncommon, and sturdy oaks, whose trunks are from eighteen inches to two feet in diameter, are seen in open groves, with luxuriant grasses and climbing plants growing beneath them."

A more recent authority is Mr. J. O. Bolger, P. L. S., who explored the region in the summer of 1886 for the department of Crown Lands of Ontario, with the special object of ascertaining its fitness for settlement. His description and opinions are more valuable than the preceding and are even more optimistic. He says: "I first encountered good land at the point where the forty-ninth parallel or the first base strikes Lake of the Woods, and following up Little Grassy river, which empties into the lake a couple of miles south of this point, I found, from traveling in every direction, that the block of four townships composed of townships one and two south, ranges twenty-three and twenty-four east, contains a large percentage of the finest land I have ever seen, and the same descrip-

*Geol. Nat. Hist. Survey Canada, part F, 1887, p. 186F.

tion applies to the block of land lying westward between these townships and the Lake of the Woods. Little Grassy river is navigable for canoes for a distance of about eight miles from its mouth and the land on the shore is all good, being composed of a rich calcareous drift formation equal to any soil in the best agricultural districts of Ontario.

The timber along the river is chiefly large, thrifty poplar, mixed with some scattering oak and swamp elm, and some evergreens, such as balsam and spruce; inland, the timber changes in character somewhat from that along the river shore as large balm of Gilead, spruce, balsam and tamerac are met with more frequently and the nice open bush which prevails along the river banks is changed for a tangled, brushy undergrowth; but the character of the soil remains the same. Tamarac and spruce swamps occur frequently in this section of the country, as is the case all through this large level area of good land which lies along the banks of Rainy river. These swamps were all perfectly dry this summer, and are all capable of being made into excellent land by drainage, as they lie nearly as high as the surrounding dry lands, and only require proper ditching to take the surface water off in wet seasons. The extreme levelness of the country causes the presence of so much swamp land here, as the surface water has no means of escaping from the low-lying portions, and, consequently, the growth of moss and swamp timber is engendered. I noticed that in most cases the beds of the little streams are deep enough to form outlets for ditches and drains, and these creek beds are usually so numerous that to drain any swamp no very long ditches would be required; in nearly all the swamps through which I passed I observed the soil to be a black vegetable mould, varying in depth from one to three feet, and always underlaid by the same calcareous clay alluded to. I seldom met the muskeg proper, that is to say, the wet, shaky bog in which water is present at all seasons of the year, and which grows nothing but dwarf spruce and moss. I then paddled up Rainy river, and on both shores I found the same kind of country as I have described as being in the vicinity of Grassy river, and, as there, a good number of settlers along the river on the Canadian side, I had an opportunity to observe the soil while under cultivation, and to see the kind of crops it is capable of raising.

The soil I found to be most excellent in character, calcareous clay overlaid by a thin streak of whitish fine earth about six inches in thickness, and this again covered with a coating of vegetable mould; and these three mixed up together in the working of the land form a soil which cannot be excelled in any part of the Dominion. I saw along the river crops of potatoes, turnips, hay, oats, wheat, corn, tomatoes and cabbage, all grown to perfection this season, which shows that the climate, as well as the soil, is suitable to successful farming, especially when tomatoes ripen, as they certainly did this year, as well as I ever saw them ripen in the vicinity of Lake Ontario. * * * *

"The timber is chiefly poplar, which grows to a great size; I have seen trees over eighteen inches across the stump, and sixty feet long clear of the limbs. Balm of Gilead, too, prevails in some sections, while spruce, tamarac and balsam of thrifty growth are everywhere met with. In some places magnificent cedar abounds, large enough for telegraph poles, shingle bolts or any other use to which cedar is applied; there are some

groves of pine through this section, but it cannot be called a pine country, that is on this drift formation."

Such testimony as to the character and value of the land through which Rainy River flows, leaves little for me to say beyond expressing my entire concurrence in the opinions quoted as to the great suitability of the country for settlement and agriculture. Settlers are going in gradually and there are some excellent farms along the river front. * * * * The river affords an easy means of access, and the levelness of the country renders roads easy to build.

This agricultural district is not confined to a narrow belt of land along the river, but has, in Minnesota, an approximate area of 5,000 square miles, between Rainy lake and the Red River of the North and south of Rainy river. Over this area the annual rainfall varies from 33 inches at Rainy lake to 17 inches at St. Vincent. The absence of hills, rock outcrops and even of boulders, is remarkable, and the land is nearly all timbered. In short all the qualifications necessary for a habitable region are found in this hitherto overlooked portion of our great state. It will not be surprising to see in the Rainy River valley as dense a population as is supported by any equal area in Minnesota.

Miscellaneous resources.

As has already been stated in the description of the physical features of the district, there are waterfalls at the outlets of many of the lakes. Some of these streams are of considerable size, and their accessible power would be eagerly sought after if located in the well settled eastern states. By far the largest water power in the district is that of the Koochiching falls. Here the Rainy river descends from twenty-one to twenty-four and a half feet, the amount of fall varying with the stage of the water. It has been estimated that there are 12,000 cubic feet of water flowing over this fall every second, and the power here generated averages 30,000 horse power, with a probable minimum of 20,000 horse power. This is thus seen to be by far the largest water power in the state, much exceeding that at the falls of St. Anthony. A dam of from five to ten feet at the head of these falls, would increase the height of the falls as many feet, and would also raise the level of Rainy lake from two to seven feet, thus furnishing an immense mill-pond with an enormous supply of water for use in times of low water in the river. The value of this water power as an aid in the development of this part of the state cannot be overestimated.

Considerable trapping is done in the winter in this section of the country, and the trade in furs has been an important busi-

ness ever since the establishment of the Hudson Bay company, which still has a store at Fort Frances. Many of the inland lakes abound in white fish and lake trout and the catching and shipping of these will furnish livelihood for a considerable population as soon as there are better facilities for transporting the fish to market.

Summary.

It is only necessary here to emphasize the fact that in the Rainy Lake district there are many natural resources, aside from the gold-bearing veins, which have not yet been developed and which would make the district an important one even if it contained no gold. We wish especially to call attention to four of these natural resources which seem destined to make this district develop with rapidity: 1, the excellent farming lands; 2, the large bodies of standing timber suitable for manufacture into lumber and paper; 3, the large water power; and 4, the possibility of the existence of valuable deposits of iron ore.

II. ROUTES OF TRAVEL TO RAINY LAKE.

At present there is no railroad running into the Rainy Lake region, the nearest station being Tower, on the Duluth and Iron Range R. R., seventy miles in a direct line southeast of Rainy Lake City. It is understood that several roads are considering the advisability of extending branches into this region, and it seems probable that the summer of 1895 will witness the commencement of active preparations along these lines.

There are three principal routes by which Rainy lake may be reached, during the summer season, as follows:

1. A regular passenger train on the Duluth and Iron Range R. R. leaves Duluth at about 3 P. M. and arrives at Tower the same evening. The next morning a steamboat may be taken from Tower to the outlet of Vermilion lake, and from here a stage ride of twenty-six miles brings one to Crane lake. A tug takes passengers from this point about twenty-eight miles to Kettle falls, and from here other boats run to Rainy Lake City, Koochiching and Ft. Frances. From each of these towns all parts of Rainy lake may be reached by steamer or canoe. The trip can be made in two days, or less, from Tower. This route is the shortest and quickest for those who are in easy rail communication with Duluth, and it has been the route most frequented during the last summer.

2. The second route runs over the Great Northern R. R. to Winnipeg and from there via the Canadian Pacific R. R. to Rat Portage at the north end of Lake of the Woods. From this point steamboats may be taken through Lake of the Woods and up the Rainy river to Ft. Frances and Koochiching. This is the most comfortable route, as the boats running from Rat Portage are larger and better equipped than those on the Tower route; but it is more expensive and takes more time than the latter route.

3. The Canadian Pacific R. R. during the last summer sold tickets from Duluth to Port Arthur by steamer, and from the latter point to Rat Portage by rail. From Rat Portage the rest of trip was made as indicated above.

Persons visiting Rainy lake will frequently find it advisable to purchase a small camping outfit and a canoe and to engage a guide or woodsman, either a white man or an Indian. A person thus equipped can travel anywhere in the region; in fact it is only by means of canoes that large tracts of the Rainy Lake district and of northeastern Minnesota are visited at all.

During the winter Rainy lake can be easily reached from Tower, Mountain Iron, Hibbing or Grand Rapids by team.

To anyone contemplating a short outing we heartily recommend a trip to the Rainy Lake region and through the evergreen forests of northeastern Minnesota and its crystal lakes, teeming with white fish, pickerel, wall-eyed pike, bass and lake trout. The expenses of such a trip are comparatively small. Two persons, who are accustomed to canoeing, can start from Duluth, spend two weeks in going from Tower to Rainy lake and back again, largely or entirely by canoe, and can return to Duluth for an expense of twenty-five dollars each, including canoe, railroad fare and provisions for the entire trip. The most agreeable time of year to visit this region, either for purposes of exploration or pleasure, is during August, September and October. Usually after the first of August the insect pests of the region, mosquitoes, blackflies and sand flies, are sufficiently reduced in numbers to render life in the woods pleasant and even delightful. And in September and October the larder may be abundantly supplied with game.

Maps.

Only two maps of the Rainy Lake region, which are large enough for convenient use in exploration, have been published. The first of these is the "Rainy Lake Sheet" of the district of Rainy River, published by the Geological and Natural History Survey of Canada; it accompanies the report on this region by A. C. Lawson,* and can be obtained from the Geological Survey, Ottawa, Ontario. This map is on a scale of four miles to one inch, and on it the various rock formations are designated by different colors. It shows the Minnesota shores of Rainy lake and considerable territory to the north and west of the lake; the outlines of the bodies of water in Canadian territory are much more accurately represented than on any other map.

The second map is entitled "Map of the Rainy Lake gold district from Ft. Francis to Kettle falls," is published by Patton & Frank, Duluth, and is sold at fifty cents a copy. This is on a scale of one mile to one inch. It shows the shores of Kabetogama lake, the Minnesota shores of Rainy lake, and the subdivisions of the sections, as accurately as do the government township plats; but the Canadian shores of Rainy lake are necessarily less accurately shown.

It is hoped that the map (plate I) which accompanies this report will prove useful. The scale is three miles to one inch. It shows the different rock formations, the positions of the villages which have recently sprung up in this region, and also the more important mining locations.

OTHER REPORTS OF GOLD IN MINNESOTA.

Very few months pass in which there is not some report in the newspapers of gold discoveries somewhere in Minnesota. From one end of the state to the other, in all kinds of situations and under various possible and impossible conditions these discoveries have from time to time been reported. Most of them fail to arouse any general interest and are soon forgotten. But in some instances the fact of some real basis for the reports, or the persistence and deceptive misrepresentations of mining swindlers keep the rumors alive until the public is actually deceived and led to "take some stock" in them.

It is a fact that gold is widely disseminated in nature, and that it may be found in small quantities in the sand and gravel deposits of the river beds and lake basins of the state. But

* Report on the geology of the Rainy Lake region; Geol. and Nat. Hist. Surv. Canada. new ser., vol. 3. pp. 1F-182F, 1889.

this is in such minute quantities and in such a fine state of division that it is seldom noticed and is rarely the cause of any of these unfounded rumors. Rusty mica, either in the sand of creek beds or in rotten granite boulders, is most frequently mistaken for gold by the uninformed. Almost every week samples of this stuff are sent in for examination, and the senders are usually very loth to believe that the shiny particles have no value whatever. When unprincipled individuals make such discoveries, or find quartz veins, no matter how barren, particularly in a farming community, they sometimes make a pretense of starting mining operations, and succeed in selling considerable amounts of stock or land at inflated and fictitious valuations.

I. REDWOOD FALLS "GOLD MINE."

A good illustration of this class of mining operations is furnished by those of the Minnesota Gold Mining and Refining company. For several months this corporation furnished reports to the daily papers of the wonderful gold quartz found in the Minnesota River valley near Redwood Falls, or more properly speaking, near Delhi, about eight miles from Redwood Falls. These news items recorded the progress of explorations at the "mine" owned by this company. Shafts were being sunk; ore was being taken out, and sent away to be assayed and even in car lots to be treated; stamp mills were ordered, an electric light plant was to be erected; a village was projected; and an electric road was talked of, to accommodate the miners who would wish to go to and fro between the "mine" and Redwood Falls.

The corporation was organized with a capital stock of \$500,000 in shares of \$10 each, and stock was offered for sale at \$6 per share, a valuation of \$300,000 for the property. The officers of the company were active in disposing of this stock, and represented their ore to have a value of \$40 to \$95 per ton; saying also that single assays had given results as high as \$2,960 per ton. Finding that many citizens of the state, who could ill afford to throw away any money, were likely to invest in this stock, one of the writers made a visit to the "mine" and took samples of the rock for assay.

The developments were rather disappointing to one who had read the newspaper stories. Situated in the Minnesota River valley, but a few feet above the water, was a test pit less than 20 feet deep. This was the "mine." The "plant" consisted

of a board shanty, a windlass and two buckets. The large force of men for whose convenience an electric road was to be built eight miles, consisted of five laborers. The vein was barren quartz in a ledge of granitoid gneiss, altogether of most unpromising appearance. Upon assaying the samples procured,* no gold or silver was found. These facts were at once given to a Minneapolis newspaper and published, together with other items of a confirmatory nature, resulting in a suspension of operations at the "mine" and a rapid decline of the market price of this worthless stock. Similar swindles may again be inaugurated, and more successfully carried out. It would appear wise to have so meprecaution taken by the State against them. If it were made the duty of some state officer to inspect all reported discoveries of valuable mineral deposits and publish his opinion of them, those who were unlearned in such matters might be saved many losses, and the reputation of the community would not be so often stained by such transactions.†

II. GOLD NEAR ELY.

Of an entirely different character from the foregoing is the reported discovery of gold on lot 6, section 30, T. 63-12, near Ely, Minnesota. Indeed it has been known for some years that gold occurs in quartz veins, between Tower and Ely. Mention was made of the fact in the geological report for 1889 and assays were reported of samples, taken by members of the geological survey corps, showing gold to the amount of a dollar per ton.‡

On Oct. 14, 1894, the first blast was fired in the above mentioned property and assays of the ore thrown out from the exploring shafts have been made by many different chemists, nearly all of whom found some gold and silver. The vein has a width of five or six feet, strikes about northeast and south-

*This assay was made by Sharpless and Winchell.

†It should also be stated that the foisting of such mining schemes upon the public for the purpose of stock-selling is not always due to the ignorance or the fraudulent designs of the owners. It not infrequently happens in Minnesota, as in Arkansas and Georgia, that assayers are more guilty than the active promoters. The writer has knowledge of several such criminal acts on the part of assayers in Minnesota. There is a strong temptation to magnify the favorable results of assays. The cupidity of the owner once aroused, he easily enlists several of his friends. The assayer's business is increased by the spreading reports and he may keep the craze going for several months or years by a judicious distribution of his false returns. The State of Minnesota to-day is cursed by the practices of a few such assayers—against whom there should be some law as rigorous as against quack doctors.

N. H. WINCHELL.

‡18th Ann. Report, Minn. Geol. Sur., pp. 19, 21. 1890.

west, and has a vertical dip. It is said to be a contact vein between syenite on the northwest and greenstone on the southeast. This vein has not been seen by us, but samples from it which we have examined show a quartz fairly well mineralized with pyrite and galena, and somewhat mixed with wall rock. Situated close to the Duluth and Iron Range railway and in other respects well located for economical development and operation, a low grade ore could be profitably worked here provided it occurs in sufficient quantity. This can be determined by further exploration. The owners of this property are C. C. Prindle, A. W. Dutton, B. E. Wells and Ed. McIntosh, of Duluth.

Work of exploration is being prosecuted on the same vein in sec. 25, T. 63-13, under the direction of Morris Thomas, of Duluth.

CONCLUSION.

Concisely stated, the facts described in the foregoing pages lead to the following conclusions: There is gold in quartz veins in the vicinity of Rainy lake. As yet the development is insufficient to warrant the positive assertion that profitable gold mining operations can be conducted there; but in certain localities the prospects are full of encouragement and promise to the conservative operator.

The best portion of the district for gold, so far as at present developed, and as indicated by the appearance and nature of the veins and the geological conditions surrounding them, is not within the limits of our state. Some gold is found south of the boundary line, and its discovery was the starting point for the explorations so vigorously prosecuted during the past year. But, as in all other mining districts, the majority of the veins are not worth working, and, indeed, many of them, chiefly belonging to the class of segregated veins, contain no gold whatever. There are excellent opportunities for the investment of capital in the gold mining industry of Rainy lake; but unless selected and developed with discrimination and scientific judgment the chances are that the property chosen may not develop into a permanent and productive mine. It is our confident belief, however that the proper forces have been in operation at several points around Rainy lake to produce auriferous quartz lodes of a richness that will compare favorably with those of many other prosperous mining districts.

If the development of operations now in progress shall demonstrate the existence of extensive deposits, as we believe will be the case, the future of the district for gold mining is assured. It is even now accessible at moderate cost; fuel, water and water power are abundant, and labor cheap. Modern methods have made the cost of exploitation, even of refractory ores, much less than it was only a few years ago. With the large bodies of low grade ore which are destined to furnish the greater part of the world's output of precious metals in the future, the costs of mines and mills as advantageously situated with reference to wood and water as those at Rainy lake, have been estimated at $2.00 a ton for mining and $3.00 a ton for barrel chlorination or for treatment by the cyanide process of ores adapted to it, and from which 90 per cent. of the metal can be saved. Where practically all the gold can be extracted by amalgamation, as at present at Rainy lake, there should be a good profit on five dollar ore in permanent veins which have an average width of five feet or more.

The surprising adaptability of the soil and climate of the the Rainy River valley for agriculture, together with its stores of timber for lumber and paper manufacture and its large water power, instill in us the conviction that northern Minnesota is an empire by itself, destined in the near future to become the home of a large and prosperous community engaged in the occupations of farming and manufacturing.

IV.

THE TOPOGRAPHICAL SURVEY OF MINNESOTA*.

BY W. R. HOAG.

The needs of the people, which are thought to fall to the government or to the State for supply, are, as a rule, slow in receiving just recognition. Wherever this tardiness becomes sufficiently pronounced to warrant it, private capital steps in and frequently supplies the need much more quickly and fully than public sentiment would have justified congress or legislatures in doing. Tradition is strong, and we are slow to delegate to the Nation or State the control of those institutions which are now serving the people acceptably. Especially true is this with those having their birth and doubtful beginnings since the establishment of our government. The railroad, the telegraph and telephone, the express also, might be named as examples in point.

It is believed that the present great activity in the world of thought and letters is directly incident to the maintenance of a domestic system which imposes upon those embraced in it a tax so small as to be insufficient to pay for the actual service of such enterprises as those named, to say nothing of a good profit which, if continued long as a private enterprise, they must afford their owners.

While the question of imposing upon those who employ a public agency little or none, burdens disproportionate with the accommodation received, in order to lighten the load of others who use it much, is a legitimate topic of discussion for the political economist, yet all are agreed that such a tax must greatly stimulate and strengthen whatever it thus unquestionably facilitates.

Who shall say what we have lost as a nation in activity and consequent development by permitting our telegraph systems to remain under private control with rates and conditions cal-

*Read before the Engineer's club of Minneapolis, Dec. 19, 1894, by W. R. Hoag, professor of Civil Engineering, University of Minnesota, and state topographer, in charge of the topographical survey.

culated in no way to encourage its wider use by the citizen, and as a rule prohibitory of such extension except where cost counts for naught or the time element is a ruling consideration. The great question of transportation incident to serving man's needs in the material world comes up with equal force. Not that we ask the question, shall the government now acquire control of the rail and waterways, but rather would not our territory have been developed much more rapidly and would not all of the strengthening and enriching effects of an efficient and economical system of transportation be present in a much larger measure than they are to-day had the government from the first developed railroad transportation the same as it has the postal system.

There is another class of needs which a civilized community soon comes to feel, but, being of a more general nature than those already noted, they have been receiving tardy recognition; and especially true is this in this country, where the national government has taken up the work only after urgent specific needs have demanded their consideration. I refer to surveys of the public domain, whether conducted with a spirit to discover the resources of the country as a purely geological and natural history survey, or as a topographical survey to meet the multiple necessities of our modern civilization.

Even the need of some scientifically consistent plan for purposes of description and partition of the land thrown open to settlement did not move congress till a large amount of such lands had been disposed of and in a manner giving the most absurd and expensive plan for farm boundaries, and unduly increasing the cost and uncertainty of all subsequent land surveys and descriptions. When, finally, the rectangular system of our public land surveys was devised and adopted about 1810, the standard of desirable accuracy was placed so low, and the execution of it by inexperienced contractors was so lamentably poor and the government inspection of it in many cases so farcical, that it has been estimated that the additional cost to the people from litigation, resulting alone from such poorly defined land boundaries directly incident to such cheap survey, has already far exceeded what would have been necessary to make an absolute topographical survey of the same, in which every important subdivision line would be given exact position by a system of triangulation and traverse, all having ultimate control in a rigid system of geodetic triangulation. In 17— it was seen that there was need of exact knowledge of our coast line,

both for developing and protecting the shipping interests and for purposes of public defense, to meet which the U. S. Coast Survey was organized, and began this great work in 1807. In 1841 the Lake Survey was organized for the definite purpose of making a geodetic survey of our shore line of the great lakes. In 1878 the Geological Survey was given the special work of conducting geological researches in the western territories and has since extended its field to the whole country, and more recently has been confining itself largely to topographical surveys, in the absence of which it found itself unable to conduct with satisfaction its geological studies. The coast lines having been about completed in 1870, except those of Alaska, the work of the Coast Survey was enlarged by act of congress in 1871 to include hydrographic and topographic work on the great rivers of the country except the Mississippi and Missouri rivers, which had been assigned to special commissions in charge of the army and navy.

The Coast Survey, with the broadened title of Coast and Geodetic Survey, was also instructed to conduct a grand system of transcontinental triangulation and precise levels for the purpose, aside from those purely scientific in character, of coördinating not only all of its own work but that of any other agency. This latter function was calculated to aid especially in fixing international and interstate boundaries, and thereby to encourage state work of somewhat like character. To still further aid each State in prosecuting its topographical survey the U. S. Coast and Geodetic Survey was authorized to conduct a separate triangulation as a basis for such surveys, in those states having in vigorous operation their own state geological surveys.

To the U. S. Coast and Geodetic Survey was also entrusted the work of conducting a magnetic survey of the country.

Congress has not seen fit to create an institution whose prime function shall be to make a complete and accurate topographical map of the territory of the United States. Nor is it likely to, since there are already a number of district surveys one of whose functions is to make such a survey of its immediate locality; moreover, the avowed purpose of one of the lines of work of its oldest survey—the Coast and Geodetic—is to assist the different States in carrying on their own topographical surveys.

A further reason that the plan of individual state surveys is likely to prevail consists in the pride each State has in discov-

ering and developing its own resources; in fact each independent State desires to supply all the needs of its citizens, so far as they can be supplied within the state, and as far as possible from its own resources.

Another difficulty, attending a general plan covering the whole country, appears when we consider that some sections of the country, on account of local difficulties, coupled with the desirability of great accuracy and full detail, might cost from two to five times as much to be adequately represented on the topographical sheet as other sections.

Again, some States from a keen sense of appreciation of the economic worth of a reliable topographical map, will need to have much more detailed work done, costing much more, than could be be carried out in other states on any general plan of equity to all. Just this thing has already happened in the state of Massachusetts when the national Geological Survey proposed to conduct for it its topographical survey if the State would meet half the expense. In arranging the details of the contract it appeared that the Geological Survey desired to do the work according to its usual plan followed elsewhere under like topographic conditions. The commission objected to this plan, claiming that the State could not afford to meet even half the expense of such a survey, as it would give them a map little better than the one they already had.

In other states, by reason of general inactivity in all matters relating to public improvement, even a map of average cost would meet no present need, and all money so expended would be lost to the country, until the State should awake to an appreciation of its true worth. On the other hand, not to carry the work along about equally in the different states would be a manifest injustice.

Another evil which must attend such general plan is the following:

Any such national survey must have at its head a director or superintendent with power to direct the details of the work—the general policy alone could be fixed by congress. That survey, dependent upon the continued favorable action of congress for maintenance will, if it be loyal to its own cause, endeavor to merit and gain the support of a majority in congress. But each congressman is, as a rule, keen to see that his State is receiving its full share of the benefits from such legislation, not receiving which he withdraws his support. A system of political trading results and friendly relations are maintained

by work in some states and promises in others sufficient to control a safe majority in congress—which must result in a shifting policy of the survey and a consequent discontinuation of the work in some states in order to resume operations in others —which changes must follow closely and actively every change in the political color of congress. In that manner a great agency, created to subserve the best interests of the people impartially in a specific work, must soon degenerate into a vast political machine, an incidental feature of it being to do topographical work, the main function being to serve congress. While this picture may seem overdrawn to some, I firmly believe that in view of the difficulties present, some of which I have specified above, no such survey could survive a sufficient length of time to even become efficiently operative without coming substantially to this condition.

Indeed, this country has already furnished proof of this inevitable tendency, and its development has been such that one familiar with the modus operandi of our national surveys can not fail to see it. All this can be easily avoided by allowing each State to take up its own work at the time and in the manner which seems to it wise—conserving all the interests of the State and receiving whatever aid from the general government it may without sacrificing its control.

Though many States are at present engaged in conducting topographical surveys, according to one plan or another, but three, Massachusetts, Connecticut and New Jersey, have completed such surveys. In fact, considering the wide gap we have nearly closed with other nations of the world in the past half century in education and science, in transportation and invention and indeed in much that contributes to the wealth and greatness of a nation, we are far behind them in appreciation of the economic worth of an accurate topographical map. As a natural result we find that few States have taken advantage of the valuable cooperation offered by the U. S. Coast and Geodetic Survey in furnishing free to the State a preliminary triangulation, which must precede as a foundation all topographical work proper, Minnesota being ninth (?) in the list to thus coöperate.

The mining engineer fully realizes the value of a reliable topographical map of that section which is to be the field of his professional labor.

The municipal engineer knows that by the aid of an accurate topographical map only can he with certainty discuss questions

relating to sources of water supply, location of reservoirs and standpipes or trace outlines of natural drainage for use in designing the most efficient and economical system of sewerage disposal.

To the sanitary engineer it becomes a valuable aid in searching out sources of contamination in wells or surface supply.

The geologist requires the aid of the topographical map for the fullest exposition of his results, especially in problems touching physical, stratigraphical and glacial geology.

The hydraulic engineer would need little else to determine the site and value of mill privileges or to study the matter of overflow of land relating thereto.

The survey is of great value in prosecuting studies in natural history and meteorology. To the civil engineer an adequate topographical map is the foundation upon which nearly all his problems must rest to insure economic solution.

It has been estimated that Massachusetts alone has paid $20,000,000 since 1836 in railway expenditures over what would have been necessary had it possessed at that time accurate topographical maps of its territory.

The army engineer can increase by one quarter the efficiency of the army by supplying it with topographical maps, enabling it to take advantage of every important feature of the land. Our late civil war was undoubtedly prolonged not a little by reason of the superior knowledge of their own territory possessed by the southern generals, gained mostly by hastily prepared maps made immediately before and during the war.

To the agricultural districts the topographical map proves of greatest value. It aids in the establishment and maintenance of a scientific system of highways, which to-day is the severest tax the farmer pays. It would give a uniform and absolute means of determining land lines and corners and also data for settling all questions of land drainage or irrigation.

If more proof is desired showing the need of better maps of our territory than furnished by the original land surveys, made half a century ago, it appears in the fact that private concerns have prepared such maps and have found sale for them among the people, sufficient to justify the undertaking. The more settled portions of our state have thus been twice surveyed and mapped already and some sections many more times.

These are among the leading benefits to be derived from a reliable topographical map, and are named only as a part of

the ways in which the survey would soon come to furnish economic returns.

Some of the European States have covered their territory with repeated surveys, the earlier ones being of no present value, except to have served the very useful purpose of furnishing a field in which to develop what a topographical map must be to meet the demands of our modern civilization.

Shall we, as a State, acquire an adequate topographical map by this costly method? Or shall we, by adopting the most modern practice of the science, prove that we do not need these costly trial lessons? This question received its first answer in the State legislature of 1872, which committed us to the policy of conducting our own survey and the making of such measurements as may be necessary for an accurate map of the state.

This was the provision made in sec. 5 of the act creating the Geological and Natural History Survey, which was drafted by W. W. Folwell, introduced in the legislature by senator J. S. Pillsbury, a regent of the University, and received governor Horace Austin's approval March 1, 1872.

A second answer to this question was given in 1887, at which time, upon recommendation of N. H. Winchell, state geologist, the writer was appointed, by the superintendent of the Coast and Geodetic Survey, acting assistant and given immediate charge of their operations in this state.

The purpose of having these acting assistants appointed by the superintendent of the U. S. Coast and Geodetic Survey was to bring that part of the work requiring the most expensive instruments, rigid field methods and office reductions, under the direct supervision of one central highly professional authority. This alone insures that uniformity necessary where each state survey is an integral part of the one continental survey. It saves each State the expense of providing costly instruments needed only during the progress of the survey, as well as all instruments for conducting the primary triangulation, vertical measures, leveling and magnetics. The general direction and care of the field-work being in the hands of officers of life long experience, and the reduction of the notes made by professional computers at Washington assure that degree of accuracy which is essential to securing all of the objects of the survey; at the same time local interests are conserved by the fact that the actual field work is executed by citizens of the state, all the expenses of the work being borne by the National Survey.

Early in June, 1887, work was begun and has continued almost uninterruptedly during the summer months. During this time astronomical latitude and telegraphic longitude have been established at a station in the University grounds to serve as the absolute starting point of the survey. A primary base-line 5½ miles in length has been prepared and measured, located along Snelling avenue, St. Paul, which furnishes the element of distance to all lines. A line of precise levels has been run from the nearest sea-elevation bench-mark to this base-line, thus giving it sea elevation. From this base-line with its latitude, longitude and sea elevation accurately known, a complete system of triangulation has been extended over the greater part of Hennepin, Ramsey, Washington, Dakota, Goodhue, Wabasha and Winona counties, fully preparing this territory, amounting to about 2,500 square miles, for final topographical mapping. Besides this, other work, of the character of a reconnoissance, looking to a plan of triangulation, has been done in Chisago, Anoka, Wright, Carver, Scott, Rice, Dodge and Olmsted counties. For the past two years observations have been made, at all stations occupied for magnetic declination, with the view to making at an early date a complete magnetic map of the state for the use of all county surveyors. During the past season, employing instruments loaned by the Coast and Geodetic Survey, the Civil Engineering Department of the University has been conducting systematic observations at a magnetic station located at the experimental farm. The past season has been spent in work upon a topographical sheet covering the twin city district—including about 225 square miles, the first part of the season being devoted to the plane-table triangulation—the latter part to filling in the topography. The topographical work proper has been mostly confined to the interurban district west of Snelling avenue, and along the Mississippi river and lake and park regions of the cities where the city records would not furnish adequate details.

During the progress of the triangulation, in addition to locating the primary stations, which are 15 to 25 miles apart, the superintendent has ruled that the acting assistants will be allowed to make observations upon any other objects, such as church spires, tall chimneys, towers, etc., with the view to giving them position for use as secondary stations necessary to the state topographical survey when such objects can be subserved without extra cost to the national survey.

Since economy, as well as accuracy, demands that the primary stations be located as far distant from each other as possible, in most cases, it is of the greatest importance that these secondary points—in sufficient number and in favorable positions—be chosen and located during the progress of the primary work. Especially is this true when tall observing towers must be erected at the primary stations to overcome surrounding woods or intervening ridges, since such towers are not likely to remain in position until needed by the State in its topographical survey. If they be destroyed, the secondary and tertiary stations could not be located except by a rebuilding of the original towers, incurring additional expense and delay. During the progress of the work in Hennepin, Ramsey, Washington and Dakota counties but three towers were required, and sufficient church spires, wind mill towers, etc., could be observed for secondary points.

Quite the opposite conditions are met in Goodhue, Wabasha and Winona counties, and towers are required at nearly all stations, ranging in height from 24 to 64 feet, and but few secondary points, except windmill towers, could be established owing to the small number of objects sighted. These, from their great number and similarity, proved of very little value, since all attempts at identification proved futile. The appearance of this latter difficulty, which threatened to seriously impair the usefulness of the main triangulation led the regents of the University of Minnesota, in the spring of 1892, to appoint the writer as state topographer, with instruction to establish such secondary stations as would render the broader triangulation of value to the state topographical survey.

A state topographical survey, such as is contemplated, is based upon absolute geodetic points and conducted by actual measurements and observations, the methods and degree of accuracy throughout being sufficient to enable a map to be made capable of showing accurately all topographical features as to *distance*, *direction* and *elevation*, *i. e.*, to show accurately the position, shape, direction, character, elevation, etc., of all lakes, rivers, hills, ridges, valleys; woodland, prairie or cultivated lands; government lines and corners; all highways, railroads and canals; all buildings in the country and in villages and cities; with contour lines which would show natural drainage, the grade or pitch of all roads, the descent of all rivers, etc. Besides these, together with many other details which would be represented on the map, the survey comprehends a pub-

lished report, issued at convenient intervals during the progress of the work, which shall contain, besides the usual report on general progress of the work, expenditures and estimates, etc., a full account of all methods and description of instruments employed, and methods and results of the official reduction and computation. The principal purpose of the report is to show more accurately than can be platted on a map, the exact data gained by the field work, which accuracy is necessary for its proper continuance, and for various uses, practical and scientific. The value of such a survey to the State need not be argued, for the history of the progress of topographical surveys in all civilized countries is sufficient proof of their economic worth, the facts being that the older and more advanced nations, as England, France, Germany and Spain have been the leaders in the science of topography and geodesy, each devoting large sums of money to gain sufficiently accurate and reliable maps of its territory. The need of such maps increases with the increase in land values, and the density of population, and with the multiplied needs of an advancing civilization.

V.

HISTORICAL SKETCH OF THE DISCOVERY OF MINERAL DEPOSITS IN THE LAKE SUPERIOR REGION.*

By Horace V. Winchell.

The development of mining industry in the territory about us is so recent that its very beginning lies within the recollection of many. The earliest statistics of production commence but half a century ago, and yet how wonderful the growth and how fabulous its story! It might appear at first sight unnecessary to detail the early history of so young an industry in so new a region. But most of us are newcomers here and have taken things as we found them, without a careful investigation into the beginning of it all. We are well aware of the fact that we are in the midst of a district of marvelous natural resources. We know full well that in addition to our natural advantages American inventive skill and indomitable enterprise have pushed developments until our iron and copper mines are the wonder of the civilized world, and knowing these things we may have overlooked the day of small beginnings, and forgotten to inquire to whom we owe our present fame and wealth. It therefore seems appropriate that a brief summary of the order and date of early events should be presented before this Institute. Some of our traditions may not have a basis of fact, and others may have become more or less intermingled with fiction. It shall be our endeavor to collect the scattered data and present a narrative which shall render honor to whom honor is due for the discovery of our mineral wealth.

*From the proceedings of the Lake Superior Mining Institute, second annual meeting. Read March 7, 1894.

PREHISTORIC MINING.

Although the exploitation of our mines on a commercial scale has been in progress less than two generations, we cannot pride ourselves on being the original discovers and users of the metals they produce. I shall make quotations from the several writers on the subject, during the reading of this paper, without giving exact reference in each case. The bibliographical list appended hereto will furnish information as to the place where the reports quoted appeared. As to the use of metals by the Indians, Jackson remarks:

Long anterior to the settlement of this country by white men the children of the forest were familiar with the use of native metals, such as gold, silver, copper, and perhaps meteoric iron. Their wandering mode of life prevented the cultivation of the metallurgic art, and it is not supposed that they knew how to reduce metals from their ores by the forge or furnace. There is reason to believe that the aborigines in some parts of the country understood the art of obtaining metallic lead from the sulphuret, for the metal is so easily reduced from that ore by roasting it on an ordinary log fire, that it seems impossible for them to have failed to obtain lead if they even threw pieces of the ore into a fire. In the western states, where the lead ores occur loose in the soil and in decayed seams of the rocks, the Indians would have been most likely to have discovered the art of smelting lead. That metal is probably the only one they knew how to extract from its ores. But they understood the art of annealing the native metals by means of fire and we find proofs in the ancient workings on Lake Superior, as well as in the accounts recorded by the ancient French Jesuits, who were the first Europeans that visited the lake, that the Indians built fires on and around the masses of native copper which were too large to be removed, and after softening the metal, cut off portions with their hatchets. They understood how to fashion the malleable native metals into all the various weapons, ornaments or tools employed by them, and manifested considerable ingenuity and skill in this handicraft, but no proofs have ever been discovered that they ever made any castings of metals fusible at a high temperature. Throughout the continent, wherever gold, silver or copper is found native in the soil, or in the decayed rocks, the aboriginal inhabitants were accustomed to work these metals into various articles, by hammering them with smooth stones, affixed to a withe bound round in a groove cut in the middle of the stone. (Op. cit., p. 373.)

But these "first families of America" went farther than the use of metals found in the glacial drift. They engaged in the operations of mining, in a manner similar to that revealed in the earliest mines of Great Britain, and with equally crude implements. Of some of these prehistoric mines Whittlesey speaks as follows:

The evidences of ancient mining operations within the mineral region of Lake Superior were first brought to public notice in the winter of

1847-8. Although the Jesuit fathers frequently mention the existence of copper, and even use the term *mines*, it is clear, from the general tenor of their narratives, that they neither saw nor knew of any actual *mining* in the technical sense of that word. They announced as early as the year 1636 the presence of native copper, and refer to it as having been taken from the "mines." This was prior to the time when they had themselves visited the Great Lake, and their information was derived from Indians. At the same time they speak with equal certainty of mines of gold, *rubies and steel*; but it must be borne in remembrance that the French word is not equivalent to our English *mines*, but may be more correctly rendered veins or deposits of metals or ores.

In the "Relations" for 1859-60 after missions had been established on lake Superior, the region is reported to be "enriched in all its borders by mines of lead almost pure, and of copper all refined in pieces as large as the fist, and of great rocks which have whole veins of turquoise!" It is probable that these accounts are second-hand, and such as the Chippewas gave when they exhibited to the fathers specimens of native metal in the shape of water-worn pieces and small boulders.

Boucher, in the "Histoire veritable," etc., in 1640, asserts that "there are in this region, mines of copper, tin, antimony and lead." He speaks of a great island fifty leagues in circumference, which is doubtless the one now called Michipicoten, where "there is a very beautiful mine of copper." Copper was also found in other places in large masses "all refined"; in one instance an ingot of copper was discovered which weighed more than 800 pounds, and from which the Indians cut off pieces with their axes after having softened it by fire. All this information Boucher obtained from some French traders, and not from his own observation.

The discovery of the first ancient mine is credited to Mr. Samuel O. Knapp, agent of the Minnesota Mining company. It was in the winter of 1847-48, at the Minnesota Copper mine, and the discovery is thus related by Foster and Whitney:

In passing over a portion of the location now (1850) occupied by the Minnesota Mining Co., he observed a continuous depression in the soil, which he rightly conjectured was caused by the disintegration of a vein. There was a bed of snow on the ground three feet in depth, but it had been so little disturbed by the wind that it conformed to the inequalities of the surface. Following up these indications along the southern escarpment of the hill, where the company's works are now erected, he came to a longitudinal cavern, into which he crept, after having dispossessed several porcupines which had selected it as a place of hibernation. He saw numerous evidences to convince him that this was an artificial excavation, and, at a subsequent day, with the assistance of two or three men, proceeded to explore it. In clearing out the rubbish they found numerous stone hammers, showing plainly that they were the mining im-

plements of a rude race. At the bottom of the excavation they found a vein with ragged projections of copper, which the ancient miners had not detached. This point is east of the present works.

The following spring he explored some of the excavations to the west, where one of the shafts of the mine is now sunk. The depression was twenty-six feet deep, filled with clay and a matted mass of mouldering vegetable matter. When he had penetrated to the depth of eighteen feet, he came to a mass of native copper ten feet long, three feet wide, and nearly two feet thick, and weighing over six tons. On digging around it the mass was found to rest on billets of oak supported by sleepers of the same material. This wood, specimens of which we have preserved, by its long exposure to moisture, is dark-colored and has lost all its consistency. A knife-blade may be thrust into it as easily as into a peat-bog. The earth was so packed around the copper as to give it a firm support. The ancient miners had evidently raised it about five feet and then abandoned the work as too laborous. They had taken off every projecting point which was accessible, so that the exposed surface was smooth. Below this the vein was subsequently found filled with a sheet of copper five feet thick and of an undetermined extent vertically and longitudinally.

No less than ten cart loads of stone hammers, both with and without grooves, were found in this vicinity, besides a variety of other mining tools, among which may be mentioned cedar gutters or troughs to drain off the water, which was baled up in wooden bowls, cedar shovels, copper wedges or gads, copper chisels and spear heads, ladders formed of oak trees with the branches left projecting, wooden levers, copper mauls, etc.

There were three principal groups of these ancient diggings on Keweenaw point, viz: One a little below the forks of the Ontonagon river, another at Portage lake and a third on the waters of Eagle river. Although the old works were not always situated on good veins, yet they were regarded by practical miners as good guides to the valuable lodes. There were other veins on isle Royale and near the north shore, opposite Keweenaw point, which were extensively wrought in olden times. Whittlesey also states that in the other direction, "sixty and eighty miles to the southeast, in the iron region near Marquette are remains that are also ancient."

The date when these mines were worked and the races that wrought them are unknown. It is generally believed that the tools and implements found there are relics of the Mound Builders, and the opinion is gaining ground that the Mound Builders were ancestors of our present Indians. The discovery of two hemlock trees on which were counted 290 and 395 rings respectively, growing on the rubbish heaps of these old workings, and the further observations made by Whittlesey, showing that there were decayed trunks of trees of the same species

but of a still earlier generation lying in these troughs, are evidence that the works must have been abandoned 200 or 300 years before Columbus started on his voyage of discovery. The further fact that their existence was unknown to the Indians at the earliest time of which we have any record, is another proof of their great antiquity.*

It does not appear that the natives mined silver or gold as they did copper. It is not unlikely that they were familiar with the metals, and were aware of their occurrence in the drift, mingled with the copper, or in the rocks of Thunder bay. But since they do not occur in large masses like copper, and the Indians had no idea of fusing or smelting them into ingots, but little use was probably made of them.

EARLIEST DISCOVERIES BY WHITE PEOPLE.

The first white man to visit lake Superior was Jean Nicollet†, who was sent from Quebec by Champlain, with seven Huron Indians as his only companions, on July 1, 1634. He did not come so far west as the copper district, however, but went back through the straits of Mackinaw down to lake Michigan, after staying some time for rest at the place since called Sault Sainte Marie. It was not until 1666-67, about the time that Marquette established the Mission at Sault Sainte Marie, that we have more detailed accounts than those furnished by Lagarde in 1636 and the relation already mentioned. (1859-'60)

In the relation of Claude Allouez (1666-67), there is a chapter entitled, "Mines of copper which are found on lake Superior," from which is taken the following (Jackson's Lake Superior, p. 378):

> Up to the present time it was believed that these mines were found on only one or two of the islands; but since we have made a more careful inquiry, we have learned from the savages some secrets which they were unwilling to reveal. It was necessary to use much address in order to draw out of them this knowledge, and to discriminate between the truth and falsehood. We will not warrant, however, all we learned from their simple statements, since we shall be able to speak with more certainty when we have visited the places themselves, which we count on during this summer, when we shall go to find the "wandering sheep" in all quarters of this great lake. The first place where copper occurs in

*There is some evidence, still, that the Indians who were met by Cartier on the lower St. Lawrence were familiar with the processes of extracting metallic copper from the rock. Champlain gives a statement of their description in "Voyage du Sieur de Champlain", Paris, 1613, as quoted by Slafter. N. H. W.

†H. V. Winchell, *American Geologist*, Feb., 1894, p. 126.

abundance, after going above the Sault, is on an island about forty or fifty leagues therefrom, near the north shore, opposite a place called Missipiconatong.

The savages say it is a floating island, which is sometimes far off and sometimes near, according as the winds move it, driving it sometimes one way and sometimes another. They add that, a long time ago, four Indians accidentally went there, being lost in a fog, with which this island is almost always surrounded. It was long before they had any trade with the French, and they had no kettles or hatchets. Wishing to cook some food, they made use of their usual method, taking stones which they picked up on the shore, heating them in the fire, and throwing them into a bark trough full of water. in order to make it boil, and by this operation cook their meat. As they took up the stones they found they were nearly all of them pure copper. * * * Before leaving they collected a quantity of these stones, both large and small ones, and even some sheets of copper; but they had not gone far from the shore before a loud voice was heard, saying in anger, "Who are these robbers who have stolen the cradles and playthings of my children?" The sheets of copper were the cradles, for the Indians make them of one or two pieces of wood (a flat piece of bark with a hoop over one end), the child being swathed and bound upon the flat piece. The little pieces of copper which they took were the playthings, such pebbles being used by Indian children for a like purpose. This voice greatly alarmed them, not knowing what it could be. One said to the others it is thunder, because there are frequent storms there; others said, it is a certain genie whom they call Missibizi [Mesabi], who is reputed among these people to be the god of the waters, as Neptune was among the pagans; others said that it came from Memogovisiousis—that is to say, sea-men, similar to the fabulous Tritons, or to the Sirens, which always live in the water, with their long hair reaching to their waists. One of our savages said he had seen one in the water; nevertheless, he must have merely imagined that he did. However, this voice so terrified them that one of these four *voyageurs* died before they reached land. Shortly after, a second one of them expired; then a third; so that only one of them remained, who, returning home, told all that had taken place and died shortly afterwards. The timid and superstitious savages have never since dared to go there for fear of losing their lives. * * *

Advancing to the place called the Grand Anse (Great bay). we meet with an island three leagues from land, which is celebrated for the metal which is found there and for the thunder which takes place, because they say it always thunders there (Thunder cape). But further towards the west, on the same north shore, is the island most famous for copper, called Minong (the good place), Isle Royale. This island is twenty-five leagues in length; it is seven leagues from the main land and sixty from the head of the lake. Nearly all around the island, on the water's edge, pieces of copper are found, mixed with pebbles, but especially on the side which is opposite the south, and principally in a certain bay which is near the northeast exposure to the great lake. There are shores "tous escarpéz de terre glaize," and there are seen several layers or beds of copper, one over the other, separated or divided by other beds of earth or rocks. In the water is seen copper sand, and one can take up in spoons

grains of the metal big as an acorn, and others fine as sand. (This description probably refers to Rock harbor). * * * Advancing to the head of the lake and returning one day's journey by the south coast, there is seen in the edge of the water a rock of copper which weighs 700 or 800 pounds, and is so hard that steel can hardly cut it; but when it is heated it cuts as easily as lead. Near Point Chagaouamigon, where a mission was established, rocks of copper and plates of the same metal were found on the shores of the islands.

Last spring we bought of the savages a sheet of pure copper, two feet square, which weighed more than 100 pounds. We do not believe, however, that the mines are found on these islands, but that the copper was probably brought from Minong (Isle Royale), or from other islands, by floating ice, or over the bottom of the lake by the impetuous winds, which are very violent, particularly when they come from the northeast.

Returning still towards the mouth of the lake, following the coast on the south, at twenty leagues from the place last mentioned, we enter the river called Nantounagan (Ontonagon), on which is seen an eminence where stones and copper fall into the water, or upon the earth; they are readily found. * *

Proceeding still further, we come to the long point of land which we have compared to the arrow of the bow (Keweenaw point); at the extremity of this there is said to be a small island which is said to be only six feet square, and all copper! * * We are assured that copper is found in various places along the southern shore of the lake.

In the "Relations" for 1670-71, Pere d' Ablon remarks that "The great rock of copper of 700 or 800 pounds, and which all the travelers saw near the head of the lake, besides a quantity of pieces which are found near the shores in various places, seem not to permit us to doubt that there are somewhere the parent mines, which have not been discovered."

Baron la Hontan refers to mines of pure copper on lake Superior in his "Voyages dans l'Amérique septentrionale," published in 1688.

In the "Histoire de la Nouvelle France," by Peter Francois Xavier Charlevoix (Tome IV, p. 415) is another account of native copper. This Jesuit made a "tour of the great lakes" in 1721, but does not appear to have visited lake Superior.

Peter Kalm, a Professor of "Oeconomie" in the University of Abo, in Swedish Finland, traveled in the provinces in 1748 and 1749. He also mentions having seen masses of copper which came from the "Upper Lake," and were brought down by the Indians. He speaks of them as being found in the ground near the mouths of rivers and supposes that ice or water carried them down the sides of mountains. (London Ed., vol. 3, p. 278.)

The first attempt at modern mining appears to have been made by Alexander Henry, an Englishman, who came to North Amer-

ica soon after the conquest of Canada by the British. He is said to have been attracted by the accounts given by Carver in 1765; but this does not appear to be the case, since he was here about the same time. He was saved at the massacre of Fort Mackinaw by an Indian, who adopted him and concealed him in a cave on Mackinaw island. During the years 1765-1770 he was occupied in coasting around the shores of lake Superior looking for mineral treasure. In his "Travels," published in New York in 1809, he mentions the mass of copper near the mouth of the Ontonagon river (which was afterwards removed to Washington), and states that he cut off from it with his axe a portion weighing a hundred pounds. He passed the winter of 1767 at Michipicoten on the north shore, near which point he discovered numerous pieces of "virgin copper" and a vein of lead ore. In 1770 he associated himself with Messrs. Baxter and Bostwick in a "company of adventurers for working the mines of lake Superior." They built a barge at Point aux Pins, and laid the keel of a sloop of forty tons. Early in May, 1771, they sailed for the island of yellow sand, where they expected to find gold, and make their fortunes; but they found nothing of value. The miners examined the coast of Nanibojou, and found several veins of copper and lead, after which they returned to Point aux Pins, and erected an air furnace. "The assayer reported on the ores which they had collected, stating that the lead ore contained silver in the proportion of forty ounces to the ton; but the copper ore only a very small proportion indeed."

From Point aux Pins they crossed over to Point aux Iroquois, where Mr. Norberg, a Russian gentleman, acquainted with metals, and holding a commission in the 60th regiment, and then in garrison at Michilimackinac, accompanied them on this latter expedition. Mr. Norberg found a loose stone weighing eight pounds, of a blue color and semi-transparent. This he carried to England, where it produced in the proportion of 60 pounds of silver to a hundred weight of ore. It was deposited in the British Museum. Henry now revisited the Ontonagon river, where, besides the detached masses of copper formerly mentioned, he saw "much of the same metal bedded in the stone." They built a house and sent to the Sault for provisions. He pitched upon a spot at the commencement of mining operations, and remarks that there was a "green-colored water which tinged iron of a copper color." In digging they frequently found masses of copper, some of which were three pounds in weight.

On the 20th of June, 1772, the miners returned, after having passed the winter at the Ontonagon. Their drift had caved in during a thaw, just as they supposed they were about to come upon a solid vein of copper, but in reality just on the solid red sandstone. Henry claims that it was not for copper, but for silver. that their company was formed, and that they expected to find it mixed with either the copper or the lead. In the summer of 1773 Henry and his crew worked in solid rock on the north shore, drifting into a vein which carried some copper, but which contracted from a width of four feet to as many inches in the distance of thirty feet. What ore they had was sent to England, but the English partners had had enough, and refused to contribute further to the expenses of the enterprise. Mr. Henry thus describes the termination of affairs: "This year, therefore (1774), Mr. Baxter disposed of the sloop and other effects of the company, and paid its debts. The partners in England were, his royal highness, the Duke of Gloucester, Mr. Secretary Townshend, Sir Samuel Tuchet, Mr. Baxter, Consul of the Empress of Russia, and Mr. Cruickshank. In America, Sir William Johnson, Mr. Bostwick, Mr. Baxter, and myself. A charter had been petitioned for and obtained, but owing to our ill success it was never taken from the seal office."

COPPER MINES.

There does not appear to have been any mining in progress for nearly 70 years after the efforts made by Alexander Henry. Indeed, the occurrence of copper seems to have been almost forgotten, and was only casually mentioned. There were no explorations made of any sort, looking toward the development of mines, until Douglass Houghton was appointed state geologist of Michigan in March, 1838. Even then, and although he must have been familiar with the facts concerning the distribution of drift copper, from his former explorations made in 1831 and 1832, yet nothing appears to have been done toward investigating the copper range until 1840. In his fourth annual report, submitted February 1, 1841, we find a discussion of the general prospects for profitable mining, including a description of the veins, and a comparison of them with those of Cornwall in which the statement is made (p. 58) that "After as minute an examination of the subject as circumstances will permit, I am led to the conclusion that the only ores of the metallic minerals, occurring in those portions of the veins, which

traverse the rocks last alluded to, which can be reasonably hoped to be turned to practical account, are those of copper." He acknowledges that he was inclined to regard the occurrence of native copper as an unfavorable indication for permanence in mining until he had discovered that "that feature was more or less universal with respect to all the veins." He expresses himself in conclusion in the following conservative manner:

While I am fully satisfied that the mineral district of our state will prove a source of eventual and steadily increasing wealth to our people, I cannot fail to have before me the fear that it may prove the ruin of hundreds of adventurers, who will visit it with expectations never to be realized. The true resources have as yet been but little examined or developed, and even under the most favorable circumstances we cannot expect to see this done, but by the most judicious and economical expenditure of capital, at those points where the prospects of success are the most favorable. * * * I would by no means desire to throw obstacles in the way of those who might wish to engage in the business of mining this ore, at such time as our government may see fit to permit it, but I would simply caution those persons who would engage in this business in the hope of accumulating wealth suddenly and without patient industry and capital, to look closely before the step is taken, which will most certainly end in disappointment and ruin.

In a letter written by Dr. Houghton to Hon. Augustus Porter, member of congress from Detroit, replying to an inquiry in the "National Intelligencer," and dated December 26, 1840, we find substantial proof that he was not only acquainted with the location of some of the copper veins, but that he had actually gone into them and obtained native copper. His own statements are as follows (Bradish's "Memoir of Douglass Houghton," pp. 114-116):

Ores of zinc, lead, iron and maganese occur in the vicinity of the south shore of Lake Superior, but I doubt whether these, unless it be zinc and iron, are in sufficient abundance to prove of much importance. Ores of copper are much more abundant than either of those before mentioned, and a sufficient examination of them has been made to satisfy me that they may be made to yield an abundant supply of the metals. I do not mean by this that the copper is to be found in that region, as is the popular opinion, pure and without labor, but that capital may be safely invested in raising and smelting of these ores with profit to the capitalist. * * * The veins of ore traversing the mineral district of Lake Superior, in those portions I have examined closely, are of very frequent occurrence, and range from a few inches to fourteen feet in width. I do not now recollect (I write without a reference to field notes) that I traced any of those veins over a mile in length, and most of them less. * * * I brought from Lake Superior, on my return to Detroit this fall, from four to five tons of copper ores and am now busily engaged in making an analysis of them. Thus far they have proved equal to any ores I have ever seen, and their value for purposes of reduction cannot be doubted.

The average per cent. of metal is considerably above that of the ores of Cornwall. While speaking of the ores I am reminded of the beautiful specimens of native copper which came out with the ores in opening some of these veins. They are not very abundant, but some of them are very fine. In opening a vein, with a single blast I threw out nearly two tons of ore, and with this were many masses of native copper, from the most minute specks to about forty pounds in weight, which was the largest mass I obtained from that vein. Ores of silver occasionally occur with the copper, and in opening one vein small specks of native silver were observed. There are as yet, however, no evidences of the existence of this metal in sufficient abundance to be of practical value. * * * I hope to see the day when instead of importing the whole of the immense amount of copper and brass used in our country we may become exporters of both.

Dr. Houghton did not mention in his annual reports the location of any of the veins which he discovered, with one exception, viz., that of the green silicate of copper at Copper Harbor. The land had not at that time been thrown open for settlement or even for exploration, and he was undoubtedly reserving the details for publication in his final report, which he did not live to complete, owing to his untimely death by drowning in lake Superior, during a snow storm and gale near Eagle river, on October 13, 1845.

His official report, however, called attention to the possibilities of the region; and the cession of the land to the United States by the Chippewas, which was ratified March 12, 1843, was the signal for the commencement of a speculative craze which lasted for three years, and completely justified the fears expressed by Dr. Houghton in anticipation.

Credit for first calling attention to the copper range in a general way and for recommending its development must thus be given to Douglass Houghton. To Charles T. Jackson, however, undoubtedly belongs further credit for personally examining at a very early date and approving or condemnig many of the veins which were afterwards worked. We all know that the first mines were not in the conglomerate as at present, but in true fissure veins which crossed the conglomerate and interleaved amygdaloidal trap sheets in several systems. In these veins the copper (with a little silver) usually occurs native in masses of all sizes up to a thousand tons. The copper itself is 90 to 95 per cent. pure, and is believed to owe its origin to electro chemical action which replaced portions of both the amygdaloid and conglomerate. In his report for 1849 Jackson distinctly states his claims for priority of discovery of the value of these veins. His first explorations were made in the summer

of 1844, while in the employ of Hon. David Henshaw, who accompanied him to Keweenaw point "for the purpose of examining the country for copper." The linear survey had not at that time reached any portion of the so-called mineral lands, and Keweenaw point presented an unbroken wilderness. There was, however, already a crew of miners at work for the Lake Superior Mining company (which thus seems to have been the first incorporated organization in the field) and an encampment of United States soldiers.

These facts are mentioned by Jackson (loc. cit., p. 386), who further states that, although up to that time no such phenomena as veins of native copper had been known to exist and it would even have been "hazardous to the reputation of any geologist, who was not prepared to demonstrate the fact, to declare his belief in the practicability of mining for *native copper*;" yet in his first surveys on lake Superior (1844) he took "care to collect ample proofs of the existence not only of true veins of native copper, but also to prove the extent of the veins (as far as possible by surface observations) and that they became richer as they descended into the rocks."

He then proceeds to give the history of the first operations as follows (pp. 386-387):

The only houses which had been erected were the office of government mineral agency of General Walter Cunningham, at Porter's Island, Copper Harbor, and a rude log hut, built by Charles Gratiot, Esq., at Eagle Harbor, for the accommodation of his party of explorers. Not a road or trail existed anywhere on the point, and the tangled growth of spruce and white cedar obstructed the banks of the streams and the coast, giving a most unpromising appearance to the country, and offering great difficulties in the exploration of those regions which were considered most likely to expose the metalliferous veins. Numerous pits had been sunk at random, in the soil and rocks at Eagle Harbor, by the miners under the direction of Mr. Gratiot; but nothing considered worthy the attention of capitalists had been discovered, and the miners were about to leave the country. Mr. De Garmo Jones, of Detroit, had sent up Mr. C. C. Douglass to aid Mr. Gratiot in exploring the country, and he was associated with me in my labors, proving a very efficient assistant. Mr. Frederick W. Davis and Mr. Joseph S. Kendall accompanied me, and assisted in exploring the country for minerals.

It is well known that the results of my examination of the mineral lands on Keweenaw Point were the establishment of the fact that *native copper and native silver* existed there *in regular veins, which could be advantageously wrought by mining operations;* and that in consequence, the capitalists of the eastern States began the enterprises which have resulted in the demonstration of the practicability of mining profitably for copper and silver on Keweenaw Point. I selected the best veins for the establishment of permanent works, collected and analyzed the ores, discovered

the nature of all the minerals accompanying the copper and silver veins, and published a brief report of my researches.

In 1845 I was again sent to lake Superior, and then explored other veins, and pointed out the superiority of the *metallic lodes* over those of the *ores of copper*—a result quite contrary to the general opinion of miners and geologists, but which has been most fully sustained by subsequent experience. As was anticipated by me, the green silicate and black oxide of copper at Copper Harbor soon gave out and was abandoned. The Boston and Pittsburg Mining Company transferred their miners from that place to the metallic copper lode, which I had surveyed in company with Mr. Whitney, at the cliff, on the southwestern branch of Eagle river. This mine is well known as one of the wonders of the world, affording the largest masses of copper which have ever been seen, and yielding a considerable amount of native silver. I again surveyed those veins I had explored in 1844, and advised the opening of a mine at a place which I named Copper Falls. Operations were forthwith commenced at this place, and a new company was formed by the division of the Lake Superior Mining Company. This mine is still in operation and has given promising results. The Lake Superior Mining Company sold out their rights to the veins at Eagle Harbor, opened mines on the borders of Eagle river in 1844 and continued their operations for some years at that place.

The foregoing rather copious quotations have been made for the purpose of showing the grounds for the claim that more credit belongs to Jackson than has usually been accorded to him in the literature of the copper regions. Further accounts of his explorations may be found in the report mentioned.

There were several other explorers in the district, at this early date, whose names are on record. The vein afterwards known as the Copper Falls mine was discovered by Joseph Hempstead and C. C. Douglass in 1844 and immediately visited by Jackson. It was on lands held under lease by the Lake Superior Copper company.

Whitney speaks as follows of the discovery of the Cliff mine, belonging to the Pittsburg and Boston Mining company. (Metal Wealth, p. 275).

The discovery and opening of this mine formed an era in the history of lake Superior and are also of high interest to the country, as it was the first mine in the United States, those of coal and iron excepted, systematically and extensively wrought, and at the same time with profit. Besides this, it has a peculiar importance as being opened on a vein bearing copper exclusively in the native state, a feature entirely unknown in the history of mining previous to the discoveries on lake Superior. * * *

During the summer of 1843 a Mr. Raymond made certain locations in the lake Superior region, for which he obtained leases, three of which he disposed of to parties in Pittsburg and Boston, who commenced mining in the summer of 1844. The first location was made at Copper Harbor, where the outcrop of a cupriferous vein on what is now called Hays's

Point, was a conspicuous object, known to the "*voyageurs*" as "the green rock," and had given a name to that beautiful harbor long before it became the center of the copper excitement. A little work was done here in the autumn of 1844, but on clearing away the ground on the opposite side of the harbor, where Fort Wilkins now stands, numerous boulders of black oxide of copper were found, evidently belonging to a vein near at hand, which was discovered in December, and proved to be a continuation of the one before worked on Hays's Point.

Mining was commenced here immediately; two shafts were sunk, about a hundred feet apart, and considerable black oxide of copper taken out, mixed with the silicate. This was very remarkable, as it is thus far the only known instance of a vein containing this as the principal ore, or in any other form than as an impure mass, mixed with the sulphuret of copper and oxides of iron and manganese, and resulting from the decomposition of the common ore, copper pyrites. This proved, however, unfortunately to be only a rich bunch in the vein of limited extent, and which gave out at the depth of a few feet, although the fissure continued. The workings were entirely confined to the conglomerate, which at that time was supposed to be as favorable to the development of the vein as any other rock. The gangue associated with the black oxide was principally calc spar, and some argillaceous and quartzose matter intermixed. Fine crystals of analcime were found connected with it. Crystallized red oxide and native copper were also obtained in fine specimens. About thirty or forty tons of black oxide were obtained in all, and sold for $4,500. The main shaft was continued down 120 feet, and levels driven each way for some distance without striking another bunch of ore, so that in 1845 the attention of the company began to be turned to exploring their extensive property, and, in Augnst of that year, the Cliff Vein was discovered by a party of explorers under the direction of a Mr. Cheny.

The vein was first observed on the summit and face of a bluff of crystalline trap, rising with a mural front to a height of nearly 200 feet above the valley of the Eagle river at its base. The break or depression made by it in the back of the ridge was quite distinct, and has since been traced to the lake and found marked by ancient excavations. At the summit of the bluff, as I saw it a few days after its discovery, it appeared to be a few inches wide, and contained native copper and specks of silver beautifully incrusted with capillary red oxide, with a gangue of prehnite. Half way down the cliff, it had expanded out to a width of over two feet, and consisted of numerous branches of laumonite, with a small percentage of metallic copper finely disseminated through it. Of course, at this time, nothing whatever was known of the varying character of the lode in different beds of rock, nor had the trap been supposed by the miners to be the principal metalliferous rock. It is now known that the vein could not be worked with profit in the rock in which it was discovered, namely, the crystalline trap or greenstone, as no vein has yet proved sufficiently metalliferous in that belt of rock to be profitably mined.

Without knowing anything of the entire change in the character of the rock which takes place at the base of the cliff, where there was a heavy accumulation of fragments of rock dislodged from above, and suspecting as little as any one else the unprecedented discoveries about to be made in the metalliferous bed beneath, I advised the clearing away and open-

ing of the vein at as low a point as possible, because it appeared to widen out and improve in depth. A shaft was sunk a few feet, a little below the edge of the bluff, and a level driven into the greenstone a short distance, but nothing was done of importance until the talus at the base of the cliff was cleared away and the vein traced into the amygdaloid. A level was then driven in upon it, and, at a depth of 70 feet, the first mass of copper was struck, a discovery of the greatest interest, since it revealed the presence of a metalliferous belt whose existence had not before been suspected, and showed the extension of the lodes of lake Superior into belts of rock of different lithological character and the variations in richness attendant on such transitions.

It may be mentioned in passing that this mine paid dividends of about a quarter of a million of dollars between 1849 and 1856.

The following account is given by Whitney of the Phœnix Mining company:

This company, as originally constituted February 22, 1844, was possessed of seven three-mile-square leases on Keweenaw Point. It was the first organized company of the Lake Superior region, and was called the "Lake Superior Copper Company." Its stock was divided into 1200 shares of which the proprietors of the leases received 400 unassessable for their interest. The first superintendent was C. H. Gratiot, who had previously engaged in digging lead in Wisconsin. The seven locations, embracing over 40 square miles, were nearly all situated in the very richest portion of the mineral region.

During the summer of 1844, Dr. C. T. Jackson examined several veins which had been discovered on the property by C. C. Douglass and others, and under his direction work was commenced October 22, 1844, on Eagle river, near the place now known as the "Old Phœnix Mine", and carried on through the year 1845, and a stamping mill and crushing-wheels, of a kind suitable for grinding drugs, were erected, but soon proved to be entirely unserviceable. Up to March 31, 1849, when the Phœnix Company was organized and took possession of the Lake Superior Company's property, the latter company had expended $105,833.40, of which about half was probably for actual mining work, but they had done little or nothing towards developing the value of the property. The principal shaft was sunk on a "pocket" of copper and silver, without any signs of a regular vein, which soon gave out entirely.

The news of these discoveries attracted people from all parts of the land. The excitement increased rapidly, and soon the craze was in full blast. It is thus described by Whitney in his Metallic Wealth of the United States (p. 249):

In 1845 many hundred "permits" or rights to select and locate on tracts of land for mining purposes, were issued by the government, and 377 leases were granted. Most of the tracts covered by these were taken at random, and without any explorations whatever; indeed a large portion of them were on rocks which do not contain any metalliferous veins at all, or in which the veins, when they do occur, are not found to be productive.

In 1846 the excitement reached its climax; the speculations in stocks were continued as long as it was possible to find a purchaser, and a serious injury was inflicted on the mining interests of the country by the unprincipled attempts to palm off worthless property as containing valuable veins. But in 1847 the bubble had burst, and the country was almost deserted. Only half a dozen companies, out of all that had been formed, were actually engaged in mining.

The issue of permits and leases having been suspended in 1846 as illegal, Congress passed, in 1847, an Act authorizing the sale of the mineral lands and a geological survey of the district. In the meantime, while this survey was going on, the companies which had continued their operation made considerable progress, new ones were formed, and lands were purchased by them after bona fide explorations and discoveries of veins; the position and character of the really metalliferous rocks began to be known, and confidence was gradually restored. At the time of the completion of the geological survey, in 1850, and the publication in the following year, of maps of the whole region, on which the range and extent of the geological formations were laid down, copper mining in the Lake Superior district had become established on a firm basis and was rapidly developing.

The discovery of the metalliferous character of the conglomerate was made by E. J. Hulbert, John Hulbert and Amos H. Scott about the first of September, 1864. The pit was located by Mr. E. J. Hulbert, who claims to have been fully convinced that the exploration would result as it did. This was a most important discovery and one which altered the entire character of mining on Keweenaw point. It was the beginning of the present regime as contrasted with that in which the veins were wrought for mass copper.

IRON ORE.

Iron ore was discovered in Nova Scotia in 1604, even before the earliest reports of copper from the Lake Superior country. The discovery was reported by the Sieur de Monts, Lieutenant General of Acadia, appointed by Henry IV of France. In the province of Quebec iron ore was found in 1667; and in Ontario about 1800. The first iron furnace in Canada was established at Three Rivers, near Quebec, about 1630, and is the one mentioned by Kalm, in the work already quoted.

The reports of Dr. Houghton and his assistants C. C. Douglass and Bela Hubbard, for the years 1839 and 1840, and the reports of David Dale Owen for the same years, contain references to iron ores of recent geological age in the southern part of Michigan and Wisconsin. Houghton must even have had some knowledge of iron ores in the metamorphic rocks of the Upper Peninsula, for in his report for 1841 he says: "Although hematite ore is abundantly disseminated through all the rocks of the metamorphic group, it does not appear in sufficient quan-

tity at any one point that has been examined to be of practical importance." On this quotation Brooks remarks (Geol. Sur. Mich., 1869-73, Vol. 1, p. 11):

At this date Dr. Houghton had traversed the south shore of lake Superior five times, in a small boat or canoe, on geological investigations. It is therefore probable that up to 1841 no Indian traditions worthy of credence in regard to large deposits of iron ore, had come to his knowledge. As there are, so far as known, no considerable outcrops or iron ore, which come nearer than seven miles to the shore of the lake, it is plain that investigations, based on observations taken along the shore only, could have determined no more than its probable existence, which is plainly indicated in the extracts given. Dr. Houghton was not aware of the existence of iron ore in quantity until the return of Mr. Burt's party of surveyors to Detroit in the fall of 1844, his examinations in the interior of the country having been confined to the copper region. Attention at that early period was entirely directed to searching for ores of more value than iron, and it is worthy of remark, that the Jackson and Cleveland Iron Companies, which were the first two organized, were formed to mine copper, silver and gold.

MARQUETTE RANGE.

The actual discovery of iron ore was made by Wm. A. Burt, United States deputy surveyor under the direction of Dr. Houghton, who had taken the contract to finish the linear survey and unite with it geological observations of the country traversed. In 1845 Mr. Burt's party, consisting of Wm. Ives, compass-man; Jacob Houghton, barometer man; H. Mellen, R. S. Mellen, James King and two Indians, John Taylor and Michael Doner, was engaged in establishing township lines and making geological observations in the manner described.

On the 19th of September, while running the east line of township 47 N., range 27 W., using the solar compass invented by Mr. Burt, remarkable variations in the direction of the needle were noticed. In this connection Mr. Jacob Houghton, one of the party, says:

At length the compass-man called for 'all to come and see a variation that will beat them all.' As we looked at the instrument, to our astonishment the north end of the needle was traversing a few degrees to the south of west. Mr. Burt called out, 'Boys, look around and see what you can find!' We all left the line, some going to the east and some to the west, and all of us returning with specimens of iron ore, mostly gathered from outcrops. This was along the first mile from Teal lake. We carried out all the specimens we could conveniently.

A year later Mr. Burt made the following statement (Jackson's Report, 1849, Part III, p. 852):

The fourteen beds of iron ore above described are the most important ores of iron, for quantity and quality, discovered within the boundaries of this survey. * * * It may be reasonably inferred that not more

than one-seventh of the number of iron ore beds were seen during the survey of the township lines; and if this district of townships be subdivided with care in reference to mines and minerals, six times as many more will probably be found. If this view of the iron region of the Northern Peninsular of Michigan be correct, it far excels any other portion of the United States in the abundance and good qualities of its iron ores.

Mr. Bela Hubbard made a report "upon the geology and topography of the district south of lake Superior, subdivided in 1845 under the direction of Douglass Houghton, deputy surveyor" (Jackson's Report, *supra cit.*, p. 833). He makes the following statements:

The largest extent of ore noticed is in township 47, range 26, near the the corner of sections 29, 30, 31 and 32. There are here two large beds or hills of ore, made up almost entirely of granulated, magnetic or specular iron, with small quantities of spathose and micaceous iron. The more northerly of these hills extends in a direction nearly east and west for at least one-fourth of a mile, and has a breadth of little less than 1,000 feet; the whole of which forms a single mass of ore, with occasional thin strata of imperfect *chert* and jasper, and dips N. 10° E. about 30°. At its southerly outcrop, the ore is exposed in a low cliff, above which the hill rises to the height of twenty or thirty feet above the country on the south. * * * This bed of iron will compare favorably, both for extent and quality, with any known in our country.

As to the discovery of the Jackson deposit, which was the first to be mined in the Lake Superior region, we may quote from the letter from P. M. Everett to Capt. G. D. Johnson, dated Jackson, Mich., 1845, and contained in Brooks' report:

I left here on the 23d of July last and was gone until the 24th of October. * * * I had considerable difficulty in getting any one to join me in the enterprise, but I at last succeeded in forming a company of thirteen. I was appointed treasurer and agent to explore and make locations, for which last purpose we had secured seven permits from the Secretary of War. I took four men with me from Jackson and hired a guide at the Sault, where I bought a boat and coasted up the lake to Copper Harbor, which is over 300 miles from the Sault Ste. Marie. * * * We made several locations, one of which we called Iron at the time. It is a mountain of solid iron ore, 150 feet high. The ore looks as bright as a bar of iron just broken. Since coming home we have had some of it smelted, and find that it produces iron and something resembling gold —some say it is gold and copper. Our location is one mile square, and we shall send a company of men up in the spring to begin operations; our company is called the Jackson Mining Company. The actual discovery of the Jackson location was made by S. T. Carr and E. S. Rockwell, members of Everett's party, who were guided to the locality by an Indian chief named Manjekijik. The superstition of the savage not allowing him to approach the spot, Mr. Carr continued the search alone, resulting in the discovery of the outcrop, which he describes as indicated in Mr. Everett's letter. Previous to the discovery he was led to suppose from the Indian's description, that he would find silver, lead, copper or some other metal more precious than iron, as it was represented to be "bright and shiny."

July 23, 1845, articles of association of the Jackson Mining Company were executed at Jackson, Mich., and by these articles Abram V. Berry was appointed the first *President*, Frederick W. Kirtland *Secretary*, Philo M. Everett *Treasurer*, and George W. Carr and Wm. A. Ernst *Trustees.* * * * The location was secured by the permit issued to James Ganson and was described by metes and bounds, commencing at a certain large pine tree, the position of which was fixed by its course and distance from the corner of Teal lake. When the land was surveyed it was bought at $2.50 per acre.

The Cleveland Mining company was organized in the following year, the location having been discovered by Mr. Abram V. Berry, and obtained by Dr. Dassels of Cleveland. In 1846 Fairchild Ferrand explored the Jackson location and mined some ore. The Jackson company erected a forge in 1847 on the Carp river, three miles east of the mine, under the superintendency of Wm. McNair, and the first iron was made February 10, 1848, by A. N. Barney. In 1850, Mr. A L. Crawford, proprietor of iron works at Newcastle, Pa., took about five tons of Jackson ore to Pennsylvania, and worked it up. Two years later a larger amount was taken to Sharon, Pa., by general Curtis, who visited lake Superior for the purpose of securing better ore for his furnaces. In 1872 about 70 tons were sent to Sharon; and in 1856 was made the first regular shipment, amounting to 5,000 tons.

The deposit of iron ore at Republic appears to have been first discovered by J. W. Foster and S. W. Hill in the fall of 1848. In the report, presented by C. T. Jackson, of an exploration of the country lying between lake Superior and Green bay is found the following statement by Mr. Foster (loc. cit., p. 775):

After leaving the lake we saw no exposure of the rocks until we arrived at the north part of township 46, ranges 29 and 30. The river here forms a lake-like expansion, and is bounded on the northeast by a range of hills which rise abruptly to the height of nearly two hundred feet above the water.

We explored this ridge on section 1, township 46, range 30, and found that it was composed, for the most part, of nearly pure specular oxide of iron (fer oligiste). It shoots up in a perpendicular cliff, one hundred and thirteen feet in height, so pure that it is difficult to determine its mineral associations.

We passed along the base of this cliff for more than a quarter of a mile, seeking for some gap through which we might pass and gain the summit. At length, after much toil and by clambering from one point to another, we succeeded. Passing along the brow of the cliff, forty feet, the mass was comparatively pure; then succeeded a bed of quartz composed of rounded grains, with small specks of iron disseminated, and large rounded masses of the same material enclosed, constituting a conglomerate. This bed was fifteen feet in thickness, and was succeeded again by specular

iron, exposed in places to the width of one hundred feet, but the soil and trees prevented our determining its entire width. This one cliff contains iron sufficient to supply the world for ages, yet we saw neither its length nor its width, but only an outline of the mass. Its bearing could not be accurately determined, but was inferred to be north of west and south of east, with a northerly dip of 85°.

The same deposit is described in similar terms in Foster and Whitney's Lake Superior (Part II, p. 22). In his first annual report Mr. Wright states that this property was originally "explored" by S. C. Smith, and entered by James St. Clair in 1854. The Republic Iron company was not organized until October 20, 1870, and the first ore was shipped in 1872.

The great demand for iron occasioned by the Civil war caused the iron interests which were in operation at that time to assume a very successful aspect. Development progressed rapidly and, although expenses were large, the demand for ore was constant, and the prices high, so that permanent and prosperous cities like Negaunee and Ishpeming were started and sustained by the iron or mining industry of Marquette county.

MENOMINEE RANGE.

The earliest reports of iron ore on this range are furnished by those same early geologists and explorers, J. W. Foster and S. W. Hill, whose trip across the country from lake Superior to Green bay in the fall of 1848 has already been mentioned. It seems almost incredible that their observations should have lain for so long a period unverified and forgotten, while the search for iron was prosecuted in other parts of the same region. But it was actually more than twenty years before these deposits were rediscovered and thoroughly explored. Foster's first account reads as follows (Jackson, loc. cit., p. 777):

About two miles southeast of the lower falls (of the "Twin Falls" on the Menominee), near S. 30, T. 40, R. 30, there is a large bed of specular iron ore associated with the talcose and argillaceous slates. It makes its appearance on the north side of a lake, and can be traced a mile and a half in length, and in places is exposed one hundred feet in width. It bears nearly east and west, and in external characters resembles that of the iron mountain before described. This bed was first discovered by John Jacobs, from whom I derived the information, and may be regarded as the southern limit of the iron. The distance from this point to the most northerly point where iron was discovered (on the Marquette range) is more than 50 miles in a direct line. Below the falls there are heavy accumulations of drift, so that the subjacent rocks are rarely seen; and this bed of iron ore, if it cross the river, is effectually concealed.

The limestone was also observed, and a bed of marble indicated on the map which accompanied the report. The iron ore was compared with that of Elba, New York, and Missouri, and

said to excel them all in value and favorable location. It was pointed out that the natural outlet would be by way of Bay de Noquet on lake Michigan, the place where Escanaba is now situated, and that it was entirely practicable to construct a road to that point. In the "Report of the Commissioners of the Geological Survey" of Wisconsin for 1858, are the following remarks by Col. Chas. Whittlesey:

In 1850 I passed up the Menominee as far as Irwin Falls, and examined the rocks to the east of the river in Michigan. Here the magnetic and specular ores were found, and beautifully veined marbles. The system of Magnesian slates extending from Carp river, on lake Superior, westward and southwestward, which embraces the metamorphic limestones and the iron, was then traced to the state line of Wisconsin.

During the explorations of the present year, in tracing that system within this state across the Menominee river, I had the satisfaction to find that it produces here both iron and marble, in quantities that are inexhaustible.

I cannot in this note, nor until the analyses are completed, give an idea of the value of the ores, but I am satisfied that whenever a cheap mode of transportation is provided they will attract notice. Both the iron ores and the marbles exist on both sides of the river convenient to water power that is unlimited. A considerable part of the deposits of iron have hard wood near at hand suitable for coal.

Further mention of the "iron ridge" southwest of lake Antoine and near lake Fumée may be found in Foster and Whitney's Lake Superior, Vol. II, pp. 30, 31, 1851. On page 28 there is given a section taken from the manuscript of Col. Whittlesey, showing specular iron interstratified with saccharoidal limestone near a branch of Cedar river and near Little Bekuenesec falls on the Menominee river. It is also stated, in this connection, that Mr. W. A. Burt crossed a low ridge of iron ore in 1846, not far from the corner of townships 41 and 42, between ranges 29 and 30. This was not subsequently met with in running the township lines. This ore is, however, shown on the geological map of 1873.

In 1866 Thomas and Bartley Breen, of the town of Menominee, discovered the deposit which afterwards became known as the Breen mine, on sec. 22, T. 39-28. No further explorations were made until 1870, when the "fee" of the property had passed into the hands of the discoverers and Judge Ingalls and S. P. Saxton. Mr. Saxton then commenced the first active mining operations recorded in the region by sinking several test pits, and cutting two long trenches across the formation.

In 1867 the region was visited and examined geologically by Dr. Herman Credner, of Germany. His description, in German, was published in 1869, and contained frequent references to the iron ores.

The first systematic exploration was begun in 1872 under the immediate supervision of our distinguished president, Dr. Nelson P. Hulst, at that time the agent of the Milwaukee Iron company, the chief promoters of which were Mr. J. J. Hagerman and Mr. J. H. Van Dyke of Milwaukee. That the company had made a good choice in their selection of an explorer was soon proven by the discovery of the Vulcan and West Vulcan mines. Mr. Lewis Whitehead, who was Dr. Hulst's chief woodsman, was no less energetic than his superintendent, and soon had a road cut from the Breen to the Vulcan and camps erected at the latter place. In 1873 Mr. John L. Buell explored the Quinnesec property and carted the first ore (fifty-three tons) to Menominee, where it was smelted by the Menominee Furnace company.

The panic of 1873 put a damper on operations for a time But in 1877 the Menominee Mining company, of which Dr. Hulst was a member, purchased the leases of the Milwaukee Iron company, and again started the Doctor on the search for ore. He was again successful, this time discovering the celebrated Chapin mine. This was in 1878; and in 1880 the first shipments were made, amounting to 34,556 tons. The discovery of the Norway mine soon followed (in August, 1878), and thereafter the new range was entered fully in the list of ore producers from lake Superior.

PENOKEE-GOGEBIC RANGE.*

The magnetic iron ore belt of northern Wisconsin was first noted in 1848 by Dr. Randall, assistant geologist to Dr. David Dale Owen, while following the Fourth principal meridian northward.

In Owen's "Report of a Geological Survey of Wisconsin, Iowa and Minnesota" there is a "Geological report of that portion of Wisconsin bordering on the south shore of lake Superior, surveyed in the year 1849," by Charles Whittlesey. On pages 444-447 of this report (published in 1852) is a description of the "Magnetic Iron-beds of the Penokie Range." Analyses of iron ore found there are quoted which show from 56.3 per cent. to 66 per cent. of metallic iron, and the following statements are made:

> The bed of magnetic ore south of Lac des Anglais is of extraordinary thickness,—twenty-five to sixty feet. * * * In the wild and deep ravines where the Bad river breaks through the range, there is a cliff of slaty ore, most of which comes out in thin, oblique prisms, with well-de-

*H. V. Winchell, "A Bit of Iron Range History," *American Geologist*, March, 1894.

fined angles and straight edges, probably three hundred feet thick, including what is covered by the talus or fallen portions. I estimate more than one-half of this face to be ore; and in places the beds are from ten to twelve feet in thickness, with very little intermixture of quartz. There are portions of it not slaty, but thick-bedded.

The geological occurrence is fully figured and described, and the similiarity of this ore to "the extensive mines or rather mountains of iron ore in Michigan, described by Houghton, Burt, Jackson, Foster and Whitney" is also mentioned. The idea of exploitation on a large scale is conveyed in the last paragraph:

The position of the best exposures of ore which I saw is such as to require from eighteen to twenty-eight miles of transportation to reach the lake. The nearest natural harbor is in Chegwomigon bay, about twenty-five miles from the central part of the Penokie range.

The interesting origin of the name "Penokie" was given as follows by Col. Whittlesey in an article on "The Penokee Mineral Range" read before the Boston Society of Natural History in July, 1863:

In the Chippewa language the name for iron is *pewabik*; and I thought it proper to designate the mountains, where this metal exists in quantities that surprise all observers, as the "Pewabik Range." The compositor, however, transformed it to *Penokie*, a work which belongs to no language, but which is now too well fastened upon the range by usage to be changed.

Soon after the publication of Dr. Owen's report, the excitement of 1845-6 in reference to copper was repeated in reference to iron. Pre-emptors followed the surveyors, erecting their rude cabins on each quarter-section between the meridian and Lac des Anglais, a distance of eighteen or twenty miles. The iron belt is generally less than one-fourth of a mile in width, regularly stratified, dipping to the northwest, conformable to the formations, and having its outcrop along the summit of the second or southerly range.

So much iron was found there that he intended to call it the "Pewabik" range in 1850, even before the government survey of the region.

This paper was accompanied by a geological map of the range prepared by Whittlesey in 1860, on which the crest of the range and the outcrops of iron ore are marked with wonderful accuracy.

But Whittlesey was not the only geologist who observed and described the mineral wealth of this region. In 1858 Edward Daniels, one of the State Geological Commission, and prior to that time state geologist, visited the Penokee-Gogebic range and mentions it as follows in the Commissioner's report for 1858, pp. 10, 11:

The mineral resources also promise richly. The most important of these are the great deposits of iron ore found in the Penokie Mountains, about thirty miles inland from the head of Chegwomigon Bay. These iron beds follow the mountain ridge through several townships, having a direction a little north of east. * * * * The ore is principally the magnetic and brown oxide, with traces of specular iron, and occurs in seams parallel with the stratification, varying from a mere line to fifty feet in thickness; it is of good quality, well located for quarrying, and practically inexhaustible.

Another well-known scientist who saw and appreciated the ore deposits of this range was Dr. I. A. Lapham, afterward state geologist of Wisconsin. He visited the Penokee district with Daniels in 1858. His account of the trip may be seen in the Trans. Wisconsin State Agricultural Society, Vol. V, 1858-59. He there gives what is perhaps the first published map of the range, and speaks highly of the iron ore he saw there. In a report made by Dr. Lapham to the Wisconsin and Lake Superior Mining and Smelting company, dated November, 1858, and published in pamphlet form in 1860, we find the following:

It will be seen that we have already discovered good ore in such quantities as to be practically inexhaustible, situated at points accessible to water power and having bold fronts, rendering it comparatively easy to be quarried. For many years to come only the richest and most accessible ores can be brought into use, rejecting—at least for the present—all such as have too large a proportion of silica, and such as are not in a condition to be easily and cheaply removed from the natural bed.

Further full accounts of the Penokee-Gogebic range are to be found in Volume III of the Wisconsin geological reports for 1873-79, pages 100-166.

A brief description of this range by R. Pumpelly and T. B. Brooks, published in the report of the Michigan geological survey for 1872, seems to have attracted considerable attention. This report was accompanied by a map on which the belt of iron-bearing rocks is delineated in a general way.

In 1879 F. H. Brotherton directed explorations which very closely located the ore formation for the Canal company. Subsequent work of development has borne testimony to the accuracy of his field locations, all the mines since found in the district examined by him being on or very near the line at that time determined.

The first discovery of soft ore in situ and in large quantity is said to have been made by Capt. Nat. D. Moore, during the season of 1880. This was on section 15, T. 47-46, Michigan. Capt. C. P. Pease commenced explorations on the adjoining section [16] in June, 1881, for the Cambria Iron and Steel Co.,

and partially developed the Colby mine. Actual mining was begun here in October, 1884, by Capt. Moore, and the first ore was shipped on six flat cars over the Milwaukee, Lake Shore and Western railway to Milwaukee, and thence to Erie, Pa. Under the management of Mr. Joseph Sellwood this mine surpassed all predecessors in the amount of ore shipped during the first three years after it was opened.

The Sunday Lake mines were found by Geo. A. Fay, who conducted explorations in 1881 and 1882 for D. H. Merritt and others of Marquette, Mich.

During the fall of 1882 test pitting was started by Capt. Jas. A. Wood for Mr. A. L. Norrie, on the S. ½ of S. E. ¼, sec. 22, T. 47, R. 47. Ore was found almost immediately, and the great Norrie mine is the result of subsequent explorations on the same ore body.

The wave of mining stock speculation which fairly inundated the northern states during the two years following the discovery of these iron mines is of too recent date to require description. Suffice it to say that the production from the new range was simply phenomenal, doubling and trebling with unparalleled rapidity, and constituting one of the most remarkable chapters in the mining history of this remarkable country.

VERMILION RANGE.

The first account of iron ore on the Vermilion range appears in the report of state geologist H. H. Eames, published in 1866. On page 11 is this account:

The Iron Range of Lake Vermilion

is on the east end, on the stream known as Two River, which is about sixty feet wide. * * * This range is about one mile in length; it then ceases, and after passing through a swamp, another uplift is reached, from two hundred and fifty to three hundred feet high. The iron is exposed at two or three points between fifty and sixty feet in thickness; at these points it presents quite a mural face, but below it is covered with detritus of the over-capping rock. On this account its exact thickness could not be correctly ascertained. The ore is of the variety known as hematite and white steely iron, and is associated with quartzose, jasperoids and serpentine rocks. It generally has a cap rock of from three to twenty feet thick. A little to the north of this is an exposure of magnetic iron of very good quality, forming a hill parallel with the one described.

The hematitic iron has a reddish appearance from exposure to atmospheric influence; its fracture is massive and granular, color a dark steel gray. The magnetic iron ore is strongly attracted by the magnet and has polarity, is granularly massive, color iron black.

At the request of the legislature of Minnesota Col. Charles Whittlesey made a "Report of Explorations in the Mineral Regions of Minnesota during the years 1848, 1859 and 1864," published in Cleveland in 1866. In this report is a map of Vermilion lake and the Mesabi iron range. It also contains, on page 10, an announcement of the discovery of iron ore at the former locality by Eames. Here Col. Whittlesey gives it as his opinion that workable iron ore exists near enough to lake Superior to render it of practical value.

The first "shot" was put in the ore at Vermilion lake by Geo. R. Stuntz and John Mallmann in 1875, on the "south ridge." In 1884 the Duluth and Iron Range railroad was constructed from lake Superior to the mines at Tower, and mining was begun under the direction of Capt. Elisha Morcom. Afterwards, with a change of ownership, in 1886, the management passed to Mr. D. H. Bacon, under whose supervision subsequent discoveries were made and the mines developed into one of the finest plants in the country.

The mines at Ely were first opened by Mr. Jas. Sheridan and his associates in 1886, but were soon turned over to the present owners, under the superintendence of Mr. Jos. Sellwood and his mining captain, John Pengilly. The record of the Chandler has been a most creditable one. Further detailed accounts of the Vermilion range may be found in "The Iron Ores of Minnesota," Bulletin No. 6 of the geological survey of Minnesota, which was written in 1890 and published in 1891.

MESABI RANGE.*

In 1850 J. G. Norwood mentioned iron ore as occurring at Gunflint lake (D. D. Owen's report of Wisconsin, Iowa and Minnesota, p. 417), and stated that it appeared to be in the eastward continuation of the hills known farther west as the Mesabi, and which extended to Pokegama falls on the Mississippi river. He did not notice ore in sufficient quantities to impress him with its value as a merchantable ore deposit, but simply noted its occurrence near the west end of the lake.

H. H. Eames, the geologist mentioned above, was the first to note iron ore on the Mesabi range and consider it of any value. In his report of 1866, published the following year, is an account of the ore on the western end of the range, at Prairie river, together with several analyses, showing it to be

*This spelling of the name "Mesabi" is adopted because it conforms with the usage of the state and national geological surveys for many years, and is in accord with the decision of the National Board of Geographic Names.

of good quality. Mr. Eames took steps to secure title to this property and develop it; but the time had not yet come for such an enterprise to be successful.

Favorable mention is made of the Mesabi in various other geological reports, between that time and 1891. N. H. Winchell and A. H. Chester described it at some length in the seventh, ninth, tenth and eleventh reports, and the State was urged to take steps to have it developed. In the volume on the iron ores of Minnesota, however, may be found the most elaborate discussion of the rocks of this range. The views held at this time, before the actual discovery of any of the numerous deposits since opened up, are well expressed in the following quotations (op. cit., pp. 112, 160):

They [the ores of the Mesabi] are destined to play a very important part in the future development of the iron industry of the state. They occupy fourfold the area that is occupied by the Keewatin ores [Vermilion range], and they are nearer the ore-shipping points as well as the iron-using markets. It is on account of this high promise of future productiveness that they are fully described in this bulletin. * * *

There can be no reasonable doubt that in Minnesota, about the western and northwestern confines of the Lake Superior basin and extending westward to the Mississippi river, there will yet be mined in the Mesabi range even greater quantities of hematite than have been taken from that marvel of mining districts, the Penokee-Gogebic range, which blazed out with such a brilliant record only a few years ago.

The first persistent exploration of the Mesabi range for iron ore was made by the Merritt brothers, Lon and Alf., of Duluth, Minn., and to them in largest measure must be credited its unprecedently rapid development, and to a certain extent the disastrous consequences to the iron ore interests of the entire Lake Superior region during 1893. The Mountain Iron mine was found on the 16th day of November, 1890, by a crew of workmen under Capt. J. A. Nichols. In August, 1891, the next large deposit was discovered by John McCaskill, Capt. Nichols and Wilbur Merritt; this has since developed into the Biwabik group of mines. In 1892 two railroads were built to the range, and in 1893 the shipments amounted to 620,000 gross tons, a record for the first full year's shipments that has never been equalled.

CANADIAN IRON ORE.

Deposits of iron ore are known to exist in Ontario, north of lake Superior. The McKellar brothers of Fort William, have done more than any others to discover the iron ores of that vicinity. Although not yet thoroughly explored by shafting

or drilling, it is probable that there is a considerable amount of merchantable ore in the Thunder Bay district which will be of value when the country is more thickly populated. It is not likely that it will ever enter into serious competition with the ore of those portions of the Lake Superior region situated in the United States, owing to its poorer quality and greater cost of production. So far as these deposits are at present developed they do not compare favorably with those on this side of the boundary line.

SILVER.

Having devoted considerable space to a description of our two most prosperous snd profitable mining industries, it remains for us to mention more briefly the discovery of silver and gold.

The occurrence of native silver mixed with the copper of Keweenaw point and the north shore of the lake was noticed at an early date, and has already been referred to under the head of copper. The only mines around lake Superior that have been wrought for any length of time for silver alone are on the north shore, around Thunder bay. The discovery of silver grew out of explorations for copper. In 1846 Mr. William Logan spent the summer in an examination of the Canadian shore of the lake. During the same season Mr. Forrest Sheppard conducted the first explorations for the Montreal Mining company, starting on May 2 from Montreal with a small party, which was soon increased to the number of eighty or more. The coast was examined from Sault Ste. Marie to Pigeon river, a distance of about 500 miles, and eighteen locations were selected. Each location was five miles in length and two in width, thus containing ten square miles of territory. One of these locations included Silver islet, on which the silver was not discovered, however, until 21 years later. Prince's location, west of the Kaministiquia, on Thunday bay, seems to have been the scene of the first discovery of silver in what was at that time a large quantity. The vein had a width of 14 feet, composed of calcite, barite and amethystine quartz, with a metalliferous streak in the middle. Two shafts and an adit level were opened, and masses of silver several pounds in weight were taken out. It is reported that the silver carried an appreciable amount of gold. This work was abandoned about the year 1850.

In 1856-1857 the Montreal Mining company, on the advice of their superintendent, Mr. E. B. Borron, attempted to develop a mine on their location at point Mamainse. There were several veins which made a good surface showing of native copper, chalcopyrite and galena, with silver both native and in the lead sulphide. Five shafts were sunk to depths varying from 14 to 60 feet on the most promising leads. But the veins did not hold out in depth, and operations were suspended in 1857.

The Prince and Mamainse mines, however, seem to have been more highly valued for copper than for silver, and the first discovery of silver of any consequence was made by Mr. Peter McKellar in the autumn of 1866, at what afterwards became the Thunder Bay mine. About a year later the Shuniah (later called Duncan) vein was found to be silver-bearing by Mr. John McKellar and Mr. Geo. A. McVicar. This was in May, 1867. Work was prosecuted on these veins in 1869 and 1870, the expenditures at the latter mine having amounted to about half a million dollars for a total yield of $20,000, before the final suspension in 1882.

The events leading to the discovery of silver on Silver islet and the account of the "find" are given as follows by Mr. Thomas Macfarlane (Trans. Am. Inst. Min. Eng., vol. VIII, 1880, pp. 227, 228):

It was, in all likelihood, the McKellar discoveries, together with the imposition by the Ontario government of a tax of two cents per acre on Lake Superior mining lands, which prompted the Montreal Mining Company to begin a systematic exploration of their northwestern locations. For twenty-two years these had been allowed to lie almost entirely neglected. Several of them were indeed visited and explored by Mr. Pilgrim of Sault Ste. Marie and the late Mr. Harrick, P. L. S., but the results were not such as to encourage the company to proceed to active mining operations. Indeed, during the greater part of this time, the company's resources were taxed to the utmost in developing and working the Bruce copper mines. It may safely be asserted that in doing this they experienced a dead loss of $400,000, a fact which is abundantly sufficient to account for the unwillingness of the board and shareholders to risk further capital in mining operations. The causes above given were, however, enough to induce them to incur a moderate outlay for exploring their lands, and early in 1868 I was employed by the company to take charge of a party for this purpose. * * * * On the 16th of May our exploring party, consisting of six men besides myself, arrived in Thunder Bay, on board the steamer Algoma, which was heavily freighted with men and materials for working the Thunder Bay Company's mine. After visiting the latter and the Shuniah (now the Duncan) mine, and calling the attention of the men of our party to the appearance and characters of the native silver and silver glance produced by them, we started in our Mackinaw boat on the 19th southwestward for Jarvis's location. * * *

On Jarvis's Island five different veins were found, and in one of them native silver and silver glance were discovered (the former by Mr., now Dr., C. O. Brown, and the latter by Mr. Patrick Hogan), specimens of which were forwarded to Montreal. * * * On the 1st of June we left Jarvis's for Stewart's location at Pigeon river, where we remained until the 21st, making a very close exploration for a distance of three miles inland. * * * On the 21st of June we returned to Fort William, and on the 23d reached Thunder Cape and Wood's location. * * * I * * * determined to make a complete geological map of Wood's location, and arranged with my assistant, Mr. Gerald C. Brown, to have the shore line accurately surveyed. It was while engaged planting his pickets on the many islands fronting the location that Mr. Brown first landed on the rock shortly afterwards named by me "Silver Islet," and observed the vein and the galena occurring in it. I then visited the island to obtain specimens of the galena and the enclosing rock, and three men were set to work to blast out some of the galena. It was while engaged working on the islet that one of these men, Mr. John Morgan, found the first nuggets of metallic silver, close to the water's edge. A single blast was sufficient to detach all the vein rock carrying ore above the surface of the water. * * * The silver was discovered on the 10th of July [1868], and on the 15th three packages of the best specimens were shipped from Fort William to Montreal.

During the next two years Mr. Macfarlane worked on this rock in the lake, exposed to storms which sometimes swept completely over the island and tore away all their buildings and bulwarks. The Montreal company could not be induced to incur the expense necessary to mine in earnest, although the rock taken out under the water in the winter of 1869-70 yielded $16,000 when it was smelted. The property was sold in 1870 to the Silver Islet Mining company, composed of capitalists from New York and Detroit, Michigan, with Capt. W. B. Frue as superintendent.

The discovery of silver-bearing veins in the Rabbit and Silver Mountain districts was made in 1882 and 1884 respectively, by Mr. Oliver Daunais, who learned of them through an Indian named Tchiatong, who formerly worked for the geological survey and had developed quite a fondness for exploring. Mr. Daunais, having married this Indian's daughter, was enabled to overcome his reluctance to reveal his discoveries, and was conducted nearly to the spot and then told to find the veins himself, which was not a difficult matter.

There have been occasional discoveries of silver in other parts of this district; and companies have been formed to operate mines on surface showings of greater or less attractiveness. One of the most persistent attempts to mine silver ore was made in the vicinity of Ontonagon, Michigan. Mr. Austin

Corser, of that place, is said to have discovered silver ore in situ in 1856. When the land was surveyed, in 1870, he procured a preëmption on the S. W. ¼, sec. 14, 51–42, on Little Iron river, about a mile from lake Superior. In 1872 a mining craze of the regulation style set in. It reached its greatest intensity in 1874, and subsided in the following year. A stamp mill with amalgamators was erected near this place in 1875 by the Ontonagon and Superior Mining companies, under the direction of Mr. F. W. Crosby, but only about 50 tons of ore were milled. The boom collapsed, and the mines shut down, the Cleveland being the last to quit, in 1876.

GOLD.

Although mines of the yellow metal are neither numerous nor large producers individually in this section of the county, they are found on both shores of the lake, and it is not improbable that they will increase in number and productiveness during the next decade.

There are reasons for believing that the first discovery of gold was made by Dr. Douglass Houghton in 1845, not far from the present town of Negaunee. The story is told by Mr. S. W. Hill, and a voyageur named Antoine Du Noir. They agree in the statement that Dr. Houghton wandered away from camp one day and returned about dark with a bag full of specimens, in which native gold was plainly visible. He told them that they were in a gold country, and that he should not be surprised to find quantities of it in the Huron hills. A piece of the quartz found at that time was worn as a pin for many years by Mr. Jacob Houghton, a brother of the doctor. The notes of this season's work were lost in the lake at the time of Dr. Houghton's death, but the accounts of these explorers are considered trustworthy, and the discovery of the Ropes vein in this same vicinity at a later period is strong corroborative proof of their truthfulness.

In 1865 a gold boom was started in Minnesota. The ore was reported by state geologist Eames and others to have been discovered in paying quantity at Vermilion lake, 75 miles north of Duluth. A wagon road was laid out to the new Eldorado; new towns were started, shafts were sunk, and a stamp mill was taken up there and set up on Trout river. The very land subsequently found so valuable for iron ore, where the hard hematite and jasper stood out in bald knobs, a hundred feet high, was taken for gold claims. The veins, however,

proved to contain more pyrite and pyrrhotite than gold; and by 1867 the country was deserted, iron deposits and all.

In 1871 gold ore was found by Mr. Peter McKellar at Jackfish lake, near lake Shebandowan, about 70 miles northwest of Port Arthur. It was developed into the mine called the "Huronian," and worked during part of 1884 and 1885. In 1883 a 10-stamp mill was erected, but was operated only a short time, owing to the expense of getting supplies in so remote a region.

Another gold-bearing quartz vein was found by Mr. Archibald McKellar, on an island in Partridge lake, west of Lac des Mille Lacs, in 1872; and in 1875 nuggets of gold were discovered by Mr. Donald McKellar in a quartz vein at Victoria cape, on the western side of Jackfish bay, north shore of lake Superior. Nothing of importance was done to develop either of these mines.

Gold was found on Lake of the Woods in 1878 or earlier, and there has been more or less mining for the precious metal in that region ever since.

In 1881 Mr. Julius Ropes noticed gold in a vein about six miles northwest of the city of Ishpeming. Regular mining was begun here in October, 1882, and during the following summer a 5-stamp mill was erected. In 1884 a 25-stamp mill was completed and put in operation. This is the only genuine gold mine in Michigan, and *its* history has not been an enviable one.

In 1885 considerable excitement was caused by the discovery of gold three miles west of the Ropes mine on land belonging to the Lake Superior Iron Mining company. Some beautiful samples of ore were obtained, but the average did not warrant the expenditure necessary to develop a mine.

CONCLUSION.

In closing this brief history attention should be called to the fact that the majority of our metalliferous belts were discovered by official geologists in the performance of their assigned duties. In many instances the very ore deposit was found, examined, accurately located and described with a thorough appreciation of its value, a quarter of a century or more before any advantage was derived from the information thus early given to the public.

Especial mention should also be made of the distinguished services rendered to the sciences of mining and economic geology by the wonderful man from whom this beautiful city takes

its name. Dr. Douglass Houghton may be justly styled the father of mining on lake Superior. To his indomitable enterprise and courage no less than to his versatile and colossal intellect is due the credit for the right start which was made; and in many ways his broad-gauged generous spirit is still discernible in the conduct of affairs around us.

We have attempted merely to mention the discovery of our mineral deposits, and not to sketch their subsequent development. But it were not becoming in me to close without calling attention to three other classes of creditors to whom our obligation is large. Our present condition of prosperity has been rendered possible first, by our brethren from Cornwall, Austria and other parts of Europe who, leaving their home surroundings, have journeyed to our shores and devoted years of hardest manual labor in delving for Nature's hidden treasures. Their lives have been passed underground, in dark and often dangerous galleries, while the fruits of their labors have been largely reaped by others.

We are greatly indebted in the second place, to the liberal policy of our State and National Government regarding technical education. Such institutions for scientific training as the one located in this city exert an incalculable influence for good on the material conditions surrounding us as well as on the lives and characters of our inhabitants.

Third and finally, our obligation is great to the mining engineers and superintendents who have planned and directed the development of these natural resources. In a new country, confronted with new problems, with unforeseen difficulties constantly arising, they have met each obstacle as it arose, and with industrial genius reaching almost to the sublime, have snatched victory at times from the very jaws of defeat, until our mining industry stands as it does to-day—in many respects without a parallel on the face of the globe.

PARTIAL BIBLIOGRAPHY OF THE HISTORY OF MINING ON LAKE SUPERIOR.*

AGASSIZ, LOUIS, AND J. ELLIOT CABOT.

Lake Superior. Its Physical Characters, Vegetation and Animals. Boston, March, 1850, 428 pp.; *Edinburgh New Phil. Jour.*, 1850, (2), xlix, 25-33, 398, 399; *Am. Jour. Sci.*, 1850, (2), x, 83-101.

*A very complete bibliography of the geology of lake Superior is contained in Dr. M. E. Wadsworth's memoir, Bull. Mus. Com. Zool., Geol. Ser. I.

AKERMANN, H. W.

Die Kupferführenden Schichten am Lake Superior. *Sitzungs-Berichte der naturwissenschaftlichen Gesellschaft Isis in Dresden*, 1875, pp. 101-105.

ANONYMOUS.

The Copper and Iron Region of Lake Superior. Review of the work of F. C. L. KOCH. *Mining Mag.*, New York, 1853, (1), 261-268.

The Silver of the Lake Superior Mineral Region. *Mining Mag.*, New York, 1853, (1), i, 447-454, 612, 613; ii, 82, 83.

Mineral Wealth of the Lake Superior District. *Ann. of Sci. Disc.*, 1855, 309, 310.

Mineral Region of Lake Superior. *Mining Mag.*, 1858, (1), ii, 248-252.

Canada. A Geographical, Agricultural and Mineralogical Sketch. Published by authority of the Bureau of Agriculture. Quebec, 1865, 33 pp.

BARTLETT, JAS. HERBERT.

The Manufacture of Iron in Canada. *Trans. Am. Inst. Min. Eng.*, vol. xiv, 1886, pp. 508-542.

BELL, ROBERT.

The Mineral Region of Lake Superior. *Canadian Nat. and Geol.*, 1875, (2), xii, 49-51.

BLAKE, WILLIAM P.

The Mass Copper of Lake Superior Mines and the Method of Mining It. *Trans. Am. Inst. Min. Engineers*, 1875, iv, 110-112.

BLANDY, JOHN F.

Topography with Especial Reference to the Lake Superior Copper District. *Trans. Am. Inst. Mining Engineers*, 1871, i, 75-82.

Stamp Mills of Lake Superior. *Trans. Am. Inst. Min. Engineers*, vol. ii, 1874, pp. 208-215.

BORIE, JULES.

Notice sur le Lac Supérieur et ses Mines de Cuivre de la Rive Américaine. *St. Etienne Bull. Soc. Industr.*, 1860, vi, 233-284; vii, 185-252; viii, 271, 272; *Allgem. Berg u. Hütten Zeitung*, 1862, iv, 448-450, 457-460, 469-471.

BOUCHER, PIERRE.

Histoire veritable et naturelle des moeurs et productions du pays de la Nouvelle France, vulgairement dite le Canada. Paris, 1640, pp. 168, 12mo.

BRADISH, ALVAH.

Memoir of Douglass Houghton. Detroit, 1889, pp. 302, 8vo.

BROOKS, T. B.

Geological Survey of Michigan, with maps, 1869-1873, I; Part I, Iron-bearing Rocks, 319 pp.; Part II, Copper-bearing Rocks, R. PUMPELLY and A. R. MARVINE, 143 pp.; Part III, Palæozoic Rocks, CHAS. ROMINGER, 105 pp.; II, 298 pp., contains papers by Messrs. BROOKS, JULIEN, WRIGHT, JENNEY, and TUTTLE.

BURT, WILLIAM A., AND BELA HUBBARD.

Reports of William A. Burt and Bela Hubbard on the Geography, Topography, and Geology of the U. S. Surveys of the Mineral Region of the South Shore of Lake Superior for 1845, etc. In the "Mineral Region of Lake Superior," by J. HOUGHTON, Jr., and T. W. BRISTOL. Detroit, 1846. *Senate Docs.*, 1st Sess. 29th Cong., 1845-46, vii, Doc. 357, 29 pp.; 1st Sess. 31st Cong., 1849-50, iii, 803-842.

Geology and Topography of the District South of Lake Superior, 1846; *Senate Docs.*, 1st Sess. 31st Cong., 1849-50, iii, 842-932. *See* Charles T. Jackson *and* Jacob Houghton, Jr.

CALLENDER, JOHN A.

The Lake Superior Copper Mines. *Mining Mag.*, 1854, ii, 249-253.

CASS, LEWIS.

Letter from Governor Cass, of Michigan, on the advantage of purchasing the country upon Lake Superior where copper has been found. *Senate Docs.*, 2d Sess. 18th Cong., 1824-25, No. 19, 2 pp.

CHAMBERLIN, T. C.

Geology of Wisconsin, 1873-77, ii, 768 pp., with maps. Reports by Messrs. I. A. LAPHAM, O. W. WRIGHT, T. C. CHAMBERLIN, R. D. IRVING, C. E. WRIGHT and MOSES STRONG.

Geology of Wisconsin, 1873-79, iii, 763 pp., with maps. Reports by Messrs. R. D. IRVING, R. PUMPELLY, A. A JULIEN, C. E. WRIGHT, E. T. SWEET, T. B. BROOKS, A. WICHMANN, T. C. CHAMBERLIN and T. S. HUNT.

Notes on the Silver Locations of Thunder Bay. *Canadian Jour.*, 1869, (2), xii, 218-226.

CORDIER, LOUIS, AND ELIE DE BEAUMONT.

Note sur une Masse de Cuivre Natif Provenant des Rives du Lac Supérieur, aux Etats-Unis d'Amérique. *Comptes Rendus*, 1849, xxviii, 161-163; *Leonhard's Jahrbuch*, 1849, p. 470.

COURTIS, W. M.

The North Shore of Lake Superior as a Mineral-bearing District. *Trans. Am. Inst. Min. Eng.*, 1877, v, 473-487.

The Wyandotte Silver Smelting and Refining Works. *Trans. Am. Inst. Min. Engineers*, vol. ii, 1874, pp. 89-101.

The Animikie Rocks and their vein phenomena, as shown at the Duncan Mine, Lake Superior. *Trans. Am. Inst. Mining Engineers*, vol. xv, 1887, pp. 671-677.

CREDNER, HERMANN.

Beschreibung einiger charakteristischer Vorkommen des Gediegenen Kupfers auf Keweenaw Point am Oberen-See Nord-Amerikas. *Leonhard's Jahrbuch*, 1869, 1-14.

Die vorsilurischen Gebilde der "Oberen Halbinsel von Michigan" in Nord-Amerika. *Zeit. Deut. Geol. Gesell.*, 1869, xxi, 516-554.

Gewaltige Kupfermassen am Lake Superior. *Leonhard's Jahrbuch*, 1870, 86.

DAWSON, JOHN W.

On the Geological Structure and Mineral Deposits of the Promontory of Maimanse, L. Sup. *Canadian Nat. and Geol.*, 1857, ii, 1-12.

DELESSE, A.

Mines de Fer des Etats-Unis. *Annales des Mines*, 1857, (5), xii, 805-841.

DEROUX, H.

Die Kupfergruben des Oberen See's (Lake Superior.) *Journal des Mines*, vii; *Berg u. Hütten Zeit.*, 1861, pp. 305-307, 329-331.

DIEFFENBACH, OTTO.

Bemerkungen über den Kupferbergbau in den Vereinigten Staaten von Nord-Amerika. *Berg u. Hütten. Zeit.*, 1858, pp. 47, 48, 66-68, 75, 76.

DOUGLAS, JAMES.

The Native Copper Mines of Lake Superior. *Quart. Jour. Sci.*, 1874, xi, 162-180; *Canadian Nat. and Geol.*, 1874, (2), vii, 318-336.

EAMES, HENRY H.

Geological Reconnoissance of the Northern, Middle and other Counties of Minnesota. St. Paul, 1866, 58 pp.

Report of the State Geologist, Henry H. Eames, on the Metalliferous Region bordering on Lake Superior. St. Paul, 1866, 23 pp.

EGLESTON, THOMAS.

Copper Mining on Lake Superior. *Trans. Am. Inst. Min. Engineers*, 1877, vi, 275-312.

FOSTER, J. W., AND J. P. KIMBALL.

Geology and Metallurgy of the Iron Ores of Lake Superior. New York, 1865, 97 pp., with maps.

FOSTER, J. W., AND J. D. WHITNEY.

Report on the Geology and Topography of the Lake Superior Land District. Part I, Copper Lands. *Executive Docs.*, 1st Sess. 31st Cong., 1849-50, ix, No. 69, 244 pp., with map; *Am. Jour. Sci.*, 1851, (2), xii, 222-239. Part II, The Iron Region, together with the General Geology, contains additional reports by JAMES HALL, EDWARD DESOR, CHARLES WHITTLESEY and W. D. WHITNEY. *Senate Docs.*, special session, 32d Con., 1851, iii, No. 4, 406 pp., with maps; *Am. Jour. Sci.*, 1853, (2), xv, 295, 296; 1854, (2), xvii, 11-38, 181-194.

Report on the Iron District of Lake Superior. *Senate Docs.*, 2d Sess. 31st Cong., 1850-51, ii, No. 2, 147-152.

GRAY, A. B.

Report on Mineral Lands of Lake Superior. *Executive Docs.*, 1st Sess. 29th Cong., 1845-46, vii, No. 211, 23 pp., with map.

HAGER, A. D.

Ancient Mining on the Shores of Lake Superior. *Atlantic Monthly*, 1865, xv, 308-315.

HARVEY, A.

Geology of the Northwest Lake Superior. *Proc. Can. Inst.*, Toronto, 1890, 3d ser., vol. vii, pp. 218-225.

HENRY, ALEXANDER.

Travels and Adventures in Canada and the Indian Territories, between the years 1760 and 1776, in 2 parts. 8vo. New York, 1809.

HERIOT, GEORGE.

Travels through the Canadas, etc. 4to. London, 1807.

HODGE, JAMES T.

On the Mineral Region of Lake Superior. *Proc. Am. Assoc. Adv. Sci.*, 1849, ii, 301-308; *Ann. Sci. Discov.*, 1850, 260, 261.

HONTAN, BARON LA.

Voyages dans l'Amérique Septentrionale, 1688. 2 vols.

HOUGHTON, DOUGLASS.

Report on the Copper of Lake Superior, Nov. 14, 1831. In the "Discovery of the Source of the Mississppi," by H. R. Schoolcraft, pp. 287-292. New York, 1834.

Annual Reports on the Geology of Michigan. 1-5, 1838-1842. 8vo.

Metalliferous Veins of the Northern Peninsula of Michigan. *Am. Jour. Sci.*, 1841, (1), xli, 183-186; *Trans. of the Assoc. Am. Geol. and Nat.*, 1840-42, pp. 35-38; *Edinburgh New Phil. Jour.*, 1842, xxxiii, 201, 202.

Copper on Lake Superior. *Am. Jour. Sci.*, 1844, (1), xlvii, 107, 132. *See* T. B. Brooks, J. Houghton, Jr., J. H. Relfe *and* H. R. Schoolcraft.

HOUGHTON, JACOB, JR.

The Ancient Copper Miners of Lake Superior. *Iron*, 1876, (N. S.), viii, 168, 169, 199; Swineford's Copper, Iron and other Material Interests of Lake Superior. Marquette, 1876, pp. 78-89.

HOUGHTON, JACOB, JR., AND T. W. BRISTOL.

Mineral Region of Lake Superior. Detroit, 1846, 109 pp. and map. Contains Reports by Messrs. BURT, HUBBARD, D. HOUGHTON and STANNARD.

HULBERT, EDWIN J.

"Calumet-Conglomerate," an exploration and discovery made by Edwin J. Hulbert, 1854 to 1864. 8 vo. Pp. 148. Ontonagon, 1893.

HULST, NELSON P.

Report on Mines in Menominee County, Michigan. Milwaukee, Wis., 1875. 8vo. 32 pp.

INGALL, E. D.

Report on Mines and Mining on Lake Superior. *Geol. Surv. Can.*, Part H. Report for 1887, pp. 124. Montreal, 1888.

IRVING, R. D.

The Mineral Resources of Wisconsin. *Trans. Am. Inst. Min. Engineers.* Vol. viii, 1880, pp. 478-508.

JACKSON, CHAS. T.

The Copper and Silver Mines of Lake Superior. *Proc. Bost. Soc. Nat. Hist.*, 1846, ii, 110-114; *Am. Jour. Sci.*, 1846, (2), ii, 118, 119.

Report on the Mineral Lands of Lake Superior. Contains Reports by Messrs. LOCKE, CHANNING, MCNAIR and WHITNEY. *Senate Docs.*, 1st Sess. 30th Cong., 1847-48, ii, No. 2, 175-230.

Mineral Lands of Lake Superior. Contains Reports of J. W. FOSTER and J. D. WHITNEY. *Senate Docs.*, 1848-49, 2d Sess. 30th Cong., ii, No. 2, 153-163; *Executive Docs.*, 1848-49, 2d Sess. 30th Cong., iii, No. 12, 153-163.

Report on the Progress of the Geological Survey of the Mineral Lands of the United States in Michigan. *Senate Docs.*, 1848-49, 2d Sess. 30th Cong., ii, No. 2, 185-191; *Executive Docs.*, 1848-49, 2d Sess. 30th Cong., iii, No. 12, 185-191.

Copper of the Lake Superior Region. *Am. Jour. Sci.*, 1849, (2), vii, 286, 287.

Remarks on the Geology, Mineralogy and Mines of Lake Superior. *Proc. Am. Assoc. Adv. Sci.*, 1849, ii, 283-288.

Remarques sur la Géologie du District Métallifère du Lac Supérieur. *Bull. Soc. Géol. France*, 1849-50, vii, 667-673.

Report on the Geological and Mineralogical Survey of the Mineral Lands of the United States in the State of Michigan. Contains Reports by Messrs. JACKSON, FOSTER, WHITNEY, LOCKE, BARNES, BURT, HUBBARD and others. *Senate Docs.*, 1st Sess. 31st Cong., No. 5, iii, 371-935, 1849-50; *Am. Jour. Sci.*, 1851, (2), xi, 147, 148.

Remarques sur la Géologie du District Métallifère du Lac Supérieur, suivi d'une courte Description de quelques-unes des Mines de Cuivre et d'Argent. Extrait par M. DELESSE. *Annales des Mines*, 1850, (4), xvii, 103-115.

Geology, Mineralogy and Topography of the Lands around Lake Superior. *Senate Docs.*, 1851-52, 1st Sess. 32d Cong., xi, 232-244. In Andrew's Report.

Ueber den Metallführenden Distrikt am Oberen See im Staate Michigan. *Karsten's Archiv*, 1853, xxv, 656-667.

Observations sur quelques Mines des Etats-Unis et sur le Grés Rouge du Lac Supérieur. *Comptes Rendus.* 1854, xxxix, 803-807.

Sur les Mines de Cuivre du Lac Supérieur et sur une Nouveau Gisement d'Etain dans l'Etat du Maine. *Comptes Rendus*, 1869, lxix, 1082, 1083. *See* James H. Relfe.

KALM, PETER.

Resa till Norra America, 3 Dle., 8vo, Stockholm, 1753-61; German by J. P. and J. A. MURRAY, 3 vols., 8vo. Göttingen, 1754-1764; English, 3 vols., 8vo, London, 1772-1790.

KEMP, JAMES F.

The Ore Deposits of the United States. New York, 1893, 8vo, pp. 302.

KIMBALL, J. P.

On the Iron Ores of Marquette, Mich. *Am. Jour. Sci.*, 1865, (2), xxix, 290-303.

KOCH, F. C. L.

Kupfer und Eisenerze am Lake Superior. *Zeit Deut. Geol. Gesells.*, 1851, iii, 355-358.

Die Mineral-Regionen der Oberen Halbinsel Michigan's (N. A.) am Lake Superior und die Isle Royal. *Studien des Göttingischen Vereins bergmännischer Freunde, von J. F. Hausmann.* 1854, vi, 1-248; *The Mining Magazine*, New York, 1853, i, 261-268.

LAPHAM, INCREASE A.
The Penokie Iron Range. *Wis. State Agr. Trans.*, 1858-59, v, 391-400, with map. *See* T. C. Chamberlin.

LAWTON, CHAS. D.
Mines and Mineral Statistics, Michigan. Lansing, Mich., 1885-1889.

LOGAN, WILLIAM E.
Remarks on the Mining Region of Lake Superior, and a Report on Mining Locations Claimed on the Canadian Shores of the Lake. Montreal, 1847, 31 pp., with maps.
Kupfererze führende Gesteine am Oberen See. *Leonhard's Jahrbuch*, 1864, p. 741.

MACFARLANE, THOMAS.
Silver Islet. *Trans. Am. Inst. Min. Eng.*, vol. viii, 1880, pp. 226-253.
On the Geology and Silver Ore of Wood's Location, Thunder Cape, Lake Superior. *Can. Nat.*, n. s., vol. iv, 1869, pp. 37-48.

MCCRACKEN, S. B.
The State of Michigan; Embracing Sketches of its History, Position, Resources and Industries. Lansing, Mich., 1876, 8vo, pp. 136.

MCDERMOTT, WALTER.
The Silver Islet Vein, Lake Superior. *Eng. Min. Jour.*, vol. xxiii, 1877, pp. 54-70.
Silver Islet Mine, Lake Superior. *Eng. Min. Jour.*, vol. xxvi, 1878, pp. 438-439.

MCKELLAR, PETER.
Mining on the North Shore of Lake Superior. Toronto, 1874, 26 pp.

MITCHELL, SAMUEL L.
Native Copper of North America. *Medical Repository*, 1818, (2), iv, 101, 102.

MUELLER, ALB.
Ueber die Kupferminen am Oberen See im Staate Michigan, Nord Amerika. *Verhandlungen der Naturforschenden Gesellschaft in Basel*, 1857, pp. 411-438; *Leonhard's Jahrbuch*, 1857, pp. 79-82, 589-590.

MURRISH, JOHN.
Report on the Geological Survey of the Mineral Regions. *Trans. Wis. Agr. Soc.*, 1872-73, pp. 469-494.

NICHOLSON, H. ALLEYNE.
On the Geology of the Thunder Bay and Shabendowan Mining Districts on the North Shore of Lake Superior. *Quart. Jour. Geol. Soc.*, 1873, xxix, 17-24.
On the Mining District on the North Shore of Lake Superior. *Trans. of North of England Inst. of Min. and Mech. Eng.* Newcastle-on-Tyne,1874-75, xxiv, 237-249, with maps.

NOEGGERATH. JOHANN JACOB.
Von dem Gediegen-Kupfer mit Gediegen-Silber am den Gruben von Kewena Point. *Leonhard's Jahrbuch,* 1848, p. 555.

NORWOOD, JOSEPH G.
Geological Report of a Survey of Portions of Wisconsin and Minnesota, made during the years 1847, '48, '49 and '50. In "Report of a Geol. Surv. of Wisconsin, Iowa and Minnesota," by DAVID DALE OWEN. Philadelphia, 1852, pp. 213-418.

NURSEY, WALTER R.
The Menominee Iron Range, Its Cities, Industries and Resources. Milwaukee, 1891, 8vo, pp. 150.

OWEN, DAVID DALE.
Report of a Geological Survey of Wisconsin, Iowa and Minnesota; Philadelphia, 1852. 638 pp., with maps. Contains reports by WHITTLESEY and J. G. NORWOOD.

PIGGOT, A. SNOWDEN.
On Copper and Copper Mining. Philadelphia, 1858, 388 pp.; *Mining Mag.*, 1858. x, 124-142, entitled "History of the Copper Region of Lake Superior."

PORTER, GEORGE F.
Report on the Copper Rock. In THOMAS L. MCKENNEY'S "Tour to the Lakes." Baltimore, 1827, pp. 477, 478.

RIVOT, L. E.
Mémoire sur le Gisement du Cuivre Natif au Lac Supérieur. *Comptes Rendus*, 1855, xl, 1306-1309.
Voyage au Lac Supérieur. *Annales des Mines*, 1855, (5), vii, 173-328; *Mining Mag.*, 1856, (1), vi, 28-37, 99-106, 207-213, 414-418; vii, 249-255, 359-367; 1857, ix, 60-65; Traité de Métallurgie, vol. iii, pp. 265-366. Paris, 1873.
Notice sur le Lac Supérieur. *Annales des Mines*, 1856, (5), x, 365-474. Traité de Métallurgie, pp. 367-436. Paris, 1873.

ROLKER, CHARLES M.
The Allouez Mine and Ore Dressing, as Practiced in the Lake Superior Copper District. *Trans. Am. Inst. Min. Eng.*, vol. 5, 1877, pp. 584-611.

ROMINGER, CHARLES.
Observations on the Ontonagon Silver Mining District and the Slate Quarries of Huron Bay. *Geol. Surv. of Michigan*, 1876, iii, 153-166. *See* T. B. Brooks' Geol. Surv. of Michigan, 1873, i, part iii.

ROTHWELL, RICHARD P.
The Mineral Industry. Its Statistics, Technology and Trade for 1892. Vol. i, New York, 1893, 8vo, pp. 628.

ROYAL COMMISSION.
Report on the Mineral Resources of Ontario. Toronto, Ont., 1890, 8vo, pp. 566.

SAUVAGE, E.
Notice sur les Minerals de Fer du Lac Supérieur. *Annales des Mines* 1875, (7), viii, 1-35.

SCHOOLCRAFT, HENRY R.
Account of the Native Copper on the Southern Shore of Lake Superior, with Historical Citations and Miscellaneous Remarks, in a Report to the Department of War, 1821; *Am. Jour. Sci.*, 1821, (1), iii, 201 216; *Quart. Jour. Sci.*, 1822, xii, 422-423.
On the Number, Value and Position of the Copper Mines on the Southern Shore of Lake Superior. *Senate Papers*, 2d Sess. 17th Cong., 1822, Doc. 5, 33 pp.
Notice of a Recently Discovered Copper Mine on Lake Superior, with several other Localities of Minerals. *Am. Jour. Sci.*, 1824, (1), vii, 43-49.

SHEPARD, CHARLES U.
On the Copper and Silver of Keweenaw Point, Lake Superior. Proc. of the Sixth Ann. Meet. of the *Assoc. of Am. Geol. and Nat.*, New Haven, 1845, 60, 61.

SHEPHERD, FORREST.
Remarks on a Boulder Mass of Native Copper from the Southern Shore of Lake Superior. *Am. Jour. Sci.*, 1847, (2), iv, 115, 116.

SPENCER, J. W.
Lake Superior.—On the Nipigon or Copper-bearing Rocks of Lake Superior, with Notes on Copper Mining in that Region. *Canadian Nat. and Geol.*, 1878, (2), viii, 55-81.

STOCKTON, JOHN.
Report on the Mineral Lands of Lake Superior. *Senate Docs.*, 1844-45, 2d Sess. 28th Cong., xi, No 175, 22 pp., with map. Contains Reports by Messrs. J. B. CAMPBELL, GEORGE N. SANDERS, and A. B. GRAY.

SWINEFORD, A. P.
History and Review of the Copper, Iron, Silver, Slate and other Material Interests of the South Shore of Lake Superior. Marquette, Mich., 1876. Contains: Ancient Copper Miners, J. HOUGHTON, 78-89; Geology of the Lake Superior Iron District, C. E. WRIGHT, 132-145.

Report of the Commissioner of Mineral Statistics for the State of Michigan, 1884.

Annual Review of the Iron Mining and other industries of the Upper Peninsula for the year ending Dec., 1880. 8vo, pp. 177, Marquette, 1881.

WADSWORTH, M. E.

Notes on the Geology of the Iron and Copper District of Lake Superior. Cambridge, Mass., 1880. 8vo, pp. 157. *Bull. Mus. Comp. Zool., Geol. Series I.*

WHITNEY, J. D.

The Metallic Wealth of the United States. Philadelphia, Pa., 1854. 8vo, pp. 510.

Black Oxide of Copper at Copper Harbor, Lake Superior. *Proc. Bost. Soc. Nat. Hist.*, 1849, iii., 102, 103; *Ann. Sci. Discov.*, 1850, pp. 261, 262; *Am. Jour. Sci.*, 1849, (2), viii, 273, 274.

The Lake Superior Copper and Iron District. *Proc. Bost. Soc. Nat. Hist*, 1849, iii, 210, 212.

On the Occurrence of the Ores of Iron in the Azoic System. *Proc. Am. Assoc. Adv. Sci.*, 1855, ix, 209-216; *Mining Mag.*, 1856, vii, 67-73; *Am. Jour. Sci.*, (2), 1856, xxii, 38-44.

WHITTLESEY, CHARLES.

On the Ancient Mining Operations on Lake Superior. *Proc. Am. Assoc. Adv. Sci.*, 1857, xi, 42-44.

Geological Report on that portion of Wisconsin bordering on the South Shore of Lake Superior. In D. D. OWEN'S "Report of a Geol. Surv. of Wisconsin, Iowa and Minn." Philadelphia, 1852. 4to, pp. 425-473.

The Penokie Mineral Range, Wisconsin. *Proc. Bost. Soc. Nat. Hist.*, 1863, ix, 235-244.

Abstract of Remarks upon the Occurrence of Iron in Masses. *Proc. Am. Assoc. Adv. Sci.*, 1867, xvi, 97-107.

On the Origin of Mineral Veins. *Proc. Am. Assoc. Adv. Sci.*, 1876, xxv, 213-216.

Iron River Silver District, South Shore of Lake Superior. New York, 1877, pp. 8.

WILLIAMS, C. P., AND J. F. BLANDY.

Some Contributions to a Knowledge of the Constitution of the Copper Range of Lake Superior. *Am. Jour. Sci.*, 1862, (2), xxxiv, 112-120.

WILSON, DANIEL.

The Ancient Miners of Lake Superior. *Canadian Journal*, 1856, (2), i, 225-237.

WINCHELL, N. H.

Gold in the Keewatin Schists in Northern Minnesota. *18th Ann. Rep. Minn. Geol. Surv.*, 1889, pp. 19-22.

WINCHELL, N. H., AND H. V. WINCHELL.

The Iron Ores of Minnesota. *Bulletin No. 6 of the Geol. and Nat. Hist. Surv. of Minn.* Minneapolis, 1891, 8vo, pp. 430.

WINCHELL, H. V

The Mesabi Iron Range. *Twentieth Ann. Report Minn. Geol. and Nat. Hist. Surv.* Minneapolis, 1893, pp. 111-180.

A Bit of Iron Range History. *Am. Geologist*, vol. xiii, March, 1894.

WOOD, H. R.

Kaministiquia Silver Bearing Belt. *Proc. Can. Inst.*, Toronto, 1890. 3d ser., vol. vii, pp. 245-259.

WRIGHT, CHAS. E.

Annual Reports of the Commissioner of Mineral Statistics of the State of Michigan. Marquette and Lansing, Mich., 1877-1883.

VI.

LATE GLACIAL OR CHAMPLAIN SUBSIDENCE AND RE-ELEVATION OF THE ST. LAWRENCE RIVER BASIN.*

BY WARREN UPHAM.

CONTENTS.

*This paper has been written as a continuation of the investigation which was published in pages 54 to 66 of the Twenty-second Annual Report of this survey, relating to the glacial lakes which are now succeeded by the present great Laurentian lakes. It has been partially presented elsewhere in the Bulletin of the Geological Society of America, vol. vi, pp. 21-27, Nov., 1894, and in the American Journal of Science, III, vol. xlix, pp. 1-18, with map, Jan., 1895. It was also given as an address before the Western Reserve Historical Society, Cleveland, Ohio, Dec. 22, 1894.

Stages of Recession of the North American Ice-sheet.

INTRODUCTION.

Before the Ice age the northern part of the North American continent, northwestern Europe, and Patagonia, were uplifted to altitudes far above their present hight, as shown by fjords and submarine continuations of river valleys. The cool and snowy climate attending the culmination of the elevation of these areas is thought to have amassed the ice-sheets by which their glacial and modified drift were formed. Other areas in warm temperate, tropical, and equatorial latitudes, as portions of southwestern Europe and western Africa, bordering on the Bay of Biscay, the strait of Gibraltar, and the Gulf of Guinea, extending south to the Congo river, were also differentially uplifted to a known maximum vertical extent of 6,000 feet, at the mouth of the Congo, higher than now; but the geographical position of these areas forbade their envelopment by land ice like the far northern and far southern regions of these great preglacial epeirogenic uplifts.*

Under the weight of the ice-sheets each of the three great drift-bearing areas, in North America, Europe, and Patagonia, sank from their preglacial altitude, until at the time of departure of the ice and deposition of its drift they stood several hundred feet lower than now, so that their coasts were partially submerged by the sea. From the basin of lake Champlain, where marine fossiliferous beds of modified drift overlying the till were early studied by E. and C. H. Hitchcock, the time of this recession of the ice and rapid formation of its moraines, eskers and kames, valley drift plains, and deltas, forming the closing stage of the Glacial period, has been named by Dana the Champlain epoch.

Accompanying the retreat of the ice, while its burden was being removed by the gradual melting from south to north in the northern United States and southern Canada, there ensued a re-elevation by which the land was raised to its present altitude or in part somewhat higher. The inclinations then given to the originally level shore lines of the glacial lakes in the basins of the Red river of the North and lake Winnipeg and

*The dynamic causes of epeirogenic movements, and their relations to the Glacial period as the probable causes of both its beginning and end, are more fully considered in an appendix of Wright's Ice Age in North America, 1889, pp. 573-595; Am. Jour. of Science, III, vol. xlvi, pp. 114-121, Aug., 1893; Geol. Magazine, IV, vol. i, pp. 340-349, Aug., 1894.

of the river St. Lawrence show that a wave of permanent epeirogenic uplift advanced from south to north and northeast, closely following the withdrawal of the ice. In the upper Mississippi basin, on the area of the glacial lake Agassiz, and about Hudson bay, this differential uplift has varied from probably 100 feet or less near the southern boundary of the drift to 500 feet or more upon the greater part of that region.*

The Quaternary era has thus been distinguished by three general epeirogenic movements of large portions of the earth's continental areas, first, upward to great altitudes; second, downward lower than now; and third, again upward, with minor oscillations of depression, giving the present relations of land and sea. The sequence and wide extent of these movements, and their significance as probable causes of the accumulation and departure of the ice-sheets, were first pointed out by Dana. Later, the ice weight and its removal were shown by Jamieson to have been important factors, respectively, in producing the Late Glacial or Champlain downward movement and the ensuing re-elevation. With the more recent discoveries of the great depths of many submerged river channels on both the Atlantic and Pacific coasts of North America and on the west side of the eastern continent, the sufficiency of the preglacial uplifts and resulting climatic changes to account for the Pleistocence ice-sheets has been established. These strangely unique conditions, namely, great altitude of the land and accumulation of the ice-sheets, seem to have been contemporaneous, the epeirogenic uplifts having been the cause of the glaciation.

The purpose of the present paper is to review the Late Glacial downward movement which brought the Ice age to an end, and the closely ensuing moderate uplift which attended the recession of the ice-sheet, as these movements affected the basin of the St. Lawrence river. The accompanying map (Plate III) shows the maximum area covered by the ice in this region and approximate outlines of the glacial boundary at successive stages of its retreat, with the formation of glacial lakes, as somewhat fully studied in this paper. We will first note briefly the means of measuring and estimating the preglacial altitude. A measure of the greater part of the Champlain subsidence is thus obtained, to which must be added the extent of that depression of the land below its present hight. The progress

*Journal of Geology, vol. 11, pp. 383-395, May-June, 1894.

of the re-elevation will be traced by the differential uplifting of the old shore lines of the successive glacial lakes which were the precursors of the present great Laurentian lakes, and by the limits of the Champlain marine submergence. Through these studies we come to an estimate of the duration of the Postglacial period, derived from the rate of erosion of the gorge of the Niagara river below its falls. Furthermore, a comparison of the Champlain and Postglacial wave erosion and resulting beach deposits of lake Michigan with those of lake Agassiz during its portion of the Champlain epoch gives an important clue concerning the time relationship of this epoch to the later and earlier parts of Quaternary time.

Preglacial Elevation of North America.

The submerged channel and fjord of the Hudson river, continuing to a distance of 105 miles off the coast southeastward from Sandy Hook, and having a maximum sounding of 2,844 feet where the ocean bed at each side on the margin of the submarine border of the continental plateau has a depth of only 600 feet, show an uplift of the eastern side of North America at the southern limit of the ice-sheet and glacial drift to the extent of more than half a mile. Northward, the submerged fjord outlets of the Gulf of Maine, the Gulf of St. Lawrence, and Hudson bay, are reported by Spencer, from his examination of the United States Coast Survey and British Admiralty charts, to have depths, respectively, of 2,664 feet, 3,666 feet, and 2,040 feet. On the coast of California Prof. George Davidson, of the U. S. Coast Survey, has found numerous submerged valleys, sinking to depths of 2,000 to 3,120 feet where they cross the 100-fathom line of the marginal plateau. In the interior of the continent the elevation of the northern part of the Mississippi basin is thought by Prof. E. W. Hilgard, from the fluvial transportation of Archæan pebbles and cobbles to the shores of the Gulf of Mexico, to have been 4,000 to 5,000 feet higher than now. These observations, and the fjords of all our northern shores, indicate a preglacial uplift of the northern three-fourths of North America, excepting probably Alaska, which has been glaciated only in the St. Elias region and southeastward, to a vertical extent ranging from 2,000 to 5,000 feet or more above the present hight.

During the Jura-Cretaceous and Tertiary cycles of baseleveling, the St. Lawrence, Mississippi, Hudson bay, and Mackenzie drainage areas had been sculptured by stream erosion

to nearly their present general surface features of plains, plateaus, and the Appalachian-Laurentide mountain belt. At the end of the Tertiary and during early Quaternary time, the greater part of the continent appears to have been bodily elevated, with gentle marginal flexure and tilting, so that the general contour remained unchanged, while slopes of 10 to 20 feet or more per mile were given to the borders, largely now submerged, of the uplifted area. The hollows which now contain the Laurentian lakes were parts of the Tertiary river valleys and plains, with free descent to the sea. On the south this ancient Laurentian river system included some of the head streams of the Ohio river, as shown by Carll and later writers up to the recent studies of Chamberlin and Leverett.* The preglacial uplift of the country, gradually raising Canada and the northern border of the United States to a greater altitude than the Ohio and Susquehanna basins, seems to have turned some of the previously northwardly flowing streams back toward the south. Tributaries of the Tertiary river in the basin of lake Erie became affluents of the Ohio; and probably several streams in the valleys of the Finger lakes, in central New York, were reversed from their former course which had been north to the river of the lake Ontario area, being turned south into the Susquehanna for a considerable time before the maximum ice accumulation and advance.

Late Glacial Subsidence.

From the high continental elevation whose culmination was attended with the envelopment of an area of 4,000,000 square miles, or half of North America, beneath an ice-sheet averaging probably a half or three-fourths of a mile thick, there ensued a depression of this area to its present hight and chiefly lower. Throughout the areas of lake Agassiz and the St. Lawrence basin, the land is found to have sunk several hundred feet lower than now. In Maine and New Brunswick, along the St. Lawrence and Ottawa valleys, in the basin of lake Champlain, and about Hudson bay, the extent of the subsidence is known, by the marine submergence and its fossiliferous beds, to have ranged mostly from 200 to 500 feet below the present sea level; and in northern Labrador and Grinnell land, with parts of western Greenland, from 1,000 to nearly 2,000 feet.

The preglacial uplifting forces had been due probably to the gradual cooling and shrinking of the earth while mountain-

*Am. Jour. Sci., III, vol. xlvii, pp. 247-283, with four maps and eight profiles, April. 1894.

building by folds and faulting took place too slowly to permit the crust to accommodate itself, without this deformation, to the diminishing inner mass. Large tracts of the continents therefore were elevated, in comparison with other land areas and the ocean beds, since only by these changes, tending to a perpetuation of the continents, could a less volume be enclosed by the earth's crust without subtraction from its area through the formation of mountain ranges. General permanence of the continents and ocean basins, as taught by Dana, seems thus a necessary result of the epeirogenic movements required by the secular cooling and condensation of the globe. The growing tangential stress, however, aided by the weight of the ice-sheets, finally gained relief in extensive orogenic crumpling, faults, and overthrusts, along great mountain belts, as in the Himalayas, the Sierra Nevada, and the St. Elias range, all of which have been much disturbed and increased in hight during the Pleistocene period. The previously elevated lands, both of drift-bearing regions and within the tropics, then sank to approximately an isostatic condition, the ice-laden regions being carried mainly somewhat below their present levels.

On the high surface of the ice-sheets there still reigned an arctic severity of cold. For some time, as shown by Le Conte, the snow and ice accummulation went on faster than the subsidence, causing the maxima of the land depression and of the thickness and extension of the ice to be nearly contemporaneous. While the central parts of the ice-covered areas had fallen probably four or five thousand feet from their preglacial altitude, the borders of the ice were lowered apparently in general about half as much, thereby sinking closely to their present level; and this sufficed to turn the balance from glacial growth to a beginning of the final retreat. The summer heat and rains on the glacial boundary, when reduced to its present hight, melted away the ice margin faster than it could be replenished. This process gradually extended inward, giving steep gradients of the ice-front, which formed moraines whenever a series of exceptionally cool years and abundant snowfall allowed any pause or re-advance. The whole ice-sheet, through the continuance of the peripheral melting, disappeared; and meanwhile the land on which it had lain, being unburdened, was moderately re-elevated, in obedience to its law of isostasy, proportionally with the glacial melting and retreat.

The Champlain epoch was begun and ended, respectively, by the downward and upward epeirogenic movements. It comprised the time of departure of the ice-sheets, with many small and large glacial lakes temporarily formed by its receding barrier, and with marine submergence to hundreds of feet above the present shore lines. The Late Glacial subsidence appears to have been principally completed before the time of the glacial recession and accompanying deposition of the lacustrine and marine beds; but the following uplift was in progress, advancing as fast as the ice receded, from the beginning to the end of Champlain time. Indeed, considerable parts of the glaciated areas of North America and Scandinavia are still undergoing small and slow oscillatory movements, not having yet, during the short Postglacial period, fully reached isostatic repose.

Re-elevation by a Wave-like Epeirogenic Uplift.

Both the glacial retreat and the accompanying re-elevation of the land took place somewhat intermittently, or by successive steps. Many stages in the departure of the ice-sheet are shown by its series of partly parallel but often interlocking and sometimes overlapping retreatal moraines, which I have mapped, to the number of twelve, through Minnesota, North Dakota, and Manitoba, and of which a larger number have been explored and mapped by Leverett in Illinois, Indiana, and Ohio. On Long Island, Martha's Vineyard, Nantucket, and Cape Cod, I traced in 1878 the two most southern moraines of our Atlantic seaboard; and four or five others in New England have since been recognized through the observations of Profs. R. S. Tarr and C. H. Hitchcock, and of the present writer, crossing Massachusetts, Vermont, and New Hampshire. These moraines occur on the southern part of the drift-bearing area. Others farther to the north in Canada are described by Bell, Tyrrell, and Low. It is thus learned that the ice-sheet in the United States and southern Canada gradually withdrew from south to north and northeast, with occasional interruptions when it paused or for a short time re-advanced. Courses of glacial striæ and transportation of boulders (which show the direction of ice currents and the opposite direction of recession of the ice boundary at the end of the Glacial period), reported by G. M. Dawson, McConnell, and the other Canadian observers before named, in the northern part of British America, as in the Mackenzie basin, on the Telzoa river, and about Hudson

bay and strait, indicate that similarly from the north side of the continental ice-sheet its recessional melting advanced inward, which there was southward, to the central parts of the drift-bearing region.

While the vast weight of the ice was being thus removed, the lake Agassiz area was being uplifted, as shown by its much inclined highest and earliest beaches, whereas the latest and lowest beaches are nearly horizontal. This uplift is found to have advanced like a wave from Minnesota and North Dakota northward through Manitoba and northeast to Hudson bay, permanently elevating the country as now, mostly about 500 feet above the hight which it held when first uncovered by the glacial melting. Soon after the ice receded, and while it yet continued to be the northern barrier of the decreasing glacial lake, the uplift along the whole extent of lake Agassiz, more than 600 miles from south to north, was practically completed. The southern half of that lacustrine area was first raised nearly to its present hight; later, its northern half was elevated, while the southern part received only a slight increase of hight; and lastly, the basin of Hudson bay, in the center of the glaciated area of North America, has been raised from its Champlain marine submergence of 300 to 500 feet.* Part of this elevation on the shores of Hudson bay is shown by Dr. Robert Bell to have been very recent, and it is even probably still in progress.

In like manner the Champlain history of the Laurentian lakes, and the marine submergence and emergence of the St. Lawrence, Ottawa and Champlain valleys, attest a wave-like advance of the re-elevating earth-movement from south to north and northeast, and probably in Maine and the eastern Canadian provinces from the coast northwesterly, following the recession of the border of the ice-sheet.

EVIDENCE FROM THE BEACHES OF THE GLACIAL LAKES IN THE ST. LAWRENCE BASIN.

Well marked old channels of outflow are found extending southward, at the levels of the deserted beaches, from lake Agassiz and from the glacial lakes which are now represented by the diminished, but still large, modern lakes Superior, Michigan,

*Article in the Journal of Geology, before cited. Geol. and Nat. Hist. Survey of Minnesota, Eighth Annual Report, for 1879, pp. 84-90; Eleventh An. Rep., for 1892, pp. 137-153, with map; Final Report, vols. i and ii. U. S. Geological Survey, Bulletin 39 (1887), pp. 84, with map. Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, vol. iv, for 1888-89, Part E, 156 pages, with two maps and several sections.

Huron, Erie, Ontario, and Champlain. The outlets prove that the great Pleistocene water bodies which occupied these basins were lakes, not gulfs or arms of the sea; and the differential uplifts of the basins, increasing toward the central part of the area of the continental ice-sheet, show that no land barriers, but the ice itself in its retreat, held in these lakes on their northward sides.

The basin of the St. Lawrence during the glacial recession held successively, and in part contemporaneously, no less than eight important glacial lakes, distinguished by their different areas, hights, and places of outlet. They are named the Western Superior and Western Erie glacial lakes; lake Warren, the most extensive, into which the two foregoing were merged; lake Algonquin, the successor of lake Warren in the basins of lakes Huron, Michigan, and Superior; lake Lundy, the glacial representative of lake Erie; lake Iroquois, in the basin of lake Ontario; lake Hudson-Champlain; and lake St. Lawrence, into which the two last named became merged. The glacial lake St. Lawrence, which is the only one of the series hitherto unnamed, extended over the Ottawa, Champlain, and St. Lawrence valleys previous to the melting away of the ice barrier, remaining latest in the vicinity of Quebec, by which event the sea, at a lower level than the former lake, was admitted to these valleys.

*The Western Superior glacial lake.**—In the west part of the basin of lake Superior the receding ice-sheet held a lake which outflowed southward through northwestern Wisconsin, across the present watershed between the Bois Brulé and St. Croix rivers. The highest shore line of this lake at Duluth is 535 feet above lake Superior (which has a mean level 602 feet above the sea); on Mt. Josephine, about 130 miles northeast from Duluth, its hight, according to leveling by Dr. A. C. Lawson,† is 607 feet; and at L'Anse and Marquette, Mich., 175 and 225 miles east of Duluth, it is found by Mr. F. B. Taylor‡ about 590 feet above the lake. The northeastward uplift averages seven inches per mile; and the eastward ascent is approximately three inches per mile. The latest and lowest of the Western Superior lake beaches observed at Duluth, occupied

*Proc. A. A. A. S., vol. xxxii, for 1883, p. 230. Geol. and Nat. Hist. Survey of Minnesota, Final Report, vol. ii, 1888, p. 642; Twenty-second Ann. Rep., for 1893, pp. 54-65 (first use of this name). Bulletin Geol. Soc. Am., vol. ii, 1891, p. 258. Am. Geologist, vol. xi, p. 357, May, 1893; and vol. xiv, p. 63, July, 1894.

†Minnesota Geol. Survey, Twentieth Ann. Rep., for 1891, pp. 181-289, with map and profiles.

‡Am. Geologist, vol. xiii, pp. 316-327 and 365-383, with maps, May and June, 1894.

by the "boulevard" or pleasure driveway, 475 feet above the lake, on the bluffs back of the city, appears to have an ascent of only about 35 feet in the distance to Mt. Josephine, showing that the uplift of the land was quite rapidly in progress while the ice-front still maintained the lake at the St. Croix outlet. Not long after the glacial retreat passed eastward beyond Mt. Josephine and Marquette, this lake was lowered and merged with lake Warren across the lowlands of the northern peninsula of Michigan. The vertical interval between the final stage of the Western Superior lake and the level of lake Warren shown by its earliest beach at Duluth was about 60 feet. Thenceforward the outlet of lake Warren past Chicago carried away the drainage from the glacial melting and rainfall of the Superior basin.

*The Western Erie glacial lake.**—Outflowing from the southwestern end of the lake Erie basin by a large abandoned watercourse, which reaches from Ft. Wayne, Ind., where the St. Joseph's and St. Mary's rivers unite to form the Maumee, across the present watershed to the Wabash river, this glacial lake formed two distinct beaches, named by N. H. Winchell the Van Wert and Leipsic ridges, separated by a vertical interval of 15 to 20 or 25 feet. The upper or Van Wert beach, with its crest varying in altitude from 200 to 220 feet above lake Erie (whose mean hight is 573 feet above the sea), extends about 75 miles east to Findlay, Ohio, and nearly an equal distance northeast past Bryan, Ohio, to the vicinity of Adrian, Mich., if not farther. At Findlay the lake while forming this beach, as Winchell and Leverett have shown, was bounded on the north by the ice-sheet then forming the Blanchard moraine. The second or Leipsic beach of the Western Erie lake, ranging in hight from 190 to 210 feet, runs from Ft. Wayne eastward 175 miles to its termination, as described by Leverett, at the line of a later moraine close southwest of Cleveland. Northeast and north from the old outlet the Leipsic beach reaches

* G. K. Gilbert, Am. Jour. Sci., III. vol. i, pp. 339-345, with map. May, 1871; Geology of Ohio, vol. i, 1873, pp. 540-556, with two maps. N. H. Winchell, Proc. A. A. A. S., vol. xxi, for 1872, pp. 171-179; Geology of Ohio, vol. ii, 1874, pp. 56, 431-433, etc. J. S. Newberry, Geology of Ohio, vol. ii, pp. 46-65, with three maps and numerous sections. E. W. Claypole, "The Lake Age in Ohio," Trans. Geol. Soc. Edinburgh, 1887, pp. 42, with four maps. G. F. Wright, "The Ice Age in North America," 1889, chapter xv (with reproduction of Prof. Claypole's maps, that of lake Erie-Ontario being on p. 355). J. W. Spencer, Am. Jour. Sci., III, vol. xli, p. 208, with map, March, 1891; Bulletin, Geol. Soc. Am., vol. ii, 1891, pp. 465-476, with map. Frank Leverett, Am. Jour. Sci., III, vol. xliii, pp. 281-297, with map, April, 1892. Warren Upham, Bulletin, Geol. Soc. Am., vol. ii, p. 259; Minnesota Geol. Survey, Twenty-second Ann. Rep., for 1893, p. 62 (first use of the name *Western Erie glacial lake*).

about 165 miles, past Adrian and Ypsilanti to Imlay, Mich., being nearly level to Ypsilanti, but thence in the 60 miles onward to Imlay having a rise of about 65 feet, to an altitude 849 feet above the sea. With the recession of the ice-sheet and the extension of this lake to Imlay, a lower outlet was opened over the watershed between the Shiawassee and Grand rivers in Michigan, 729 feet above the sea or 148 feet above lakes Huron and Michigan, where the Western Erie glacial lake became confluent with lake Warren and was thus reduced about 30 feet, falling from the Leipsic or lower Western Erie beach to the Belmore or earliest beach of lake Warren in the Erie basin.

Upon a large area, extending from Ft. Wayne east to Cleveland and northward to Ypsilanti and Detroit, the attitude or general slopes and levels of the land have remained unchanged since the departure of the ice-sheet, for these earliest beaches and the lower beaches of lake Warren in the same area are still nearly horizontal. The whole country there, however, has been uplifted, without tilting, about 110 feet, after the end of the separate existence of the Western Erie lake, for this is the hight of the Belmore beach around the west end of lake Erie above the highest and earliest beach of lake Warren at Chicago. A greater and differential uplift, with rapid tilting of northward ascent, was taking place north and northeast of Detroit during the Belmore and lower stages of lake Warren, simultaneous with the uniform elevation of the Western Erie glacial lake area. Further we learn that about half of the uplift of 110 feet for this region has occurred before the beginning of lake Algonquin and the date of the Algonquin beach. since that beach has a hight of 602 feet near the south end of lake Huron, being 60 feet higher than the correlative sublacustrine terrace plane beneath the surface of lake Michigan near Chicago, which marks the old Algonquin shore there.

*Lake Warren.**—Like the Western Superior and Western Erie glacial lakes, the far more extensive lake Warren at the beginning of its existence occupied only the southern end of the

*J. W. Spencer, Science, vol. xi, p. 49, Jan. 27, 1888 (proposing this name in honor of Gen. G. K. Warren); Proc. A. A. A. S., vol. xxxvii, for 1888, pp. 197-199; Trans. Roy. Soc. of Canada, vol. vii, for 1889, sec. iv, p. 122; Am. Jour. Sci., III, vol. xli, pp. 201-211, with map, March, 1891; Bulletin, Geol. Soc. Am., vol. ii, pp. 465-476, with map, April, 1891; "A Review of the History of the Great Lakes," Am. Geologist, vol. xiv, pp. 289-301, Nov., 1894 (containing citations of many additional papers by Prof. Spencer and others). G. K. Gilbert, "Changes of Level of the Great Lakes," in The Forum, vol. v, pp. 417-428, June, 1888; "History of the Niagara River," in Sixth Annual Report of the Commissioners of the State Reservation at Niagara, for 1889, pp. 61-84, with eight plates (also in the Smithsonian An. Rep. for 1890, pp. 231-257); Geology of Ohio, vols. i

basin of lake Michigan. It grew northward as the ice-sheet retired, and in due time it received these two lakes to itself, expanding thus into the basin sof lakes Superior, Huron, and Erie. The m aximum development of lake Warren stretched from Thomson, Minn., above and west of Duluth, eastward to lake Nipissing, a distance of nearly 600 miles; and from Chicago, where it outflowed to the Des Plaines, Illinois, and Mississippi rivers, it extended eastward in its highest stages across the southern peninsula of Michigan, and later by way of the strait of Mackinaw and over lakes Huron, St. Clair, and Erie, to the west end of the lake Ontario basin and to Crittenden in southwestern New York. This area exceeded 100,000 square miles, being nearly equal to the glacial lake Agassiz. The Belmore and Nelson beaches, the two highest formed by lake Warren in the basins of lakes Erie, Huron, and Superior, called by Spencer the Ridgeway beach (a later name than N. H. Winchell's "Belmore ridge") in their united course about the west half of lake Erie, show that, since the fullest expansion of this great glacial lake, the whole basin of lake Superior and the country eastward to lake Nipissing have been uplifted 400 to 550 or 600 feet, in comparison with Chicago and the southern part of the lake Michigan basin, while the uplift at Cleveland has been about 115 feet, and at Crittenden, N. Y., not less than 260 feet (more probably about 300 feet).

In the vicinity of Chicago, lake Warren formed three beaches, belonging to lake levels successively about 45 to 50 feet, 15 feet, and 30 feet above lake Michigan. That the beach

and ii. Frank Leverett, paper before cited; "Raised Beaches of Lake Michigan," Trans. Wisconsin Academy of Sciences, Arts, and Letters, vol. vii, pp. 177-192 (read Dec. 30, 1887). A. C. Lawson, "Sketch of the Coastal Topograpy of the North Side of Lake Superior, with Special Reference to the Abandoned Strands of Lake Warren," Minnesota Geol. Survey, Twentieth An. Rep., for 1891, pp. 181-289, with map, profiles, and figures from photographs. F. B. Taylor, Am. Jour. Sci., III, vol. xliii, pp. 210-218, March, 1892 (Mackinac island); Bulletin Geol. Soc. Am., vol. v. pp. 620-626, with maps, April, 1894 (lake Nipissing); Am. Geologist, vol. xiii, pp. 316-327 (Green bay) and 365-383 (south coast of lake Superior), with maps, May and June, 1893; id., vol. xiv. pp. 273-289 (east of Georgian bay), with map, Nov., 1894. The highest beach on Mackinac island, which Mr. Taylor calls the "Algonquin beach," seems to be correlative with his Nelson and higher beaches in the vicinity of lake Nipissing, regarded in this paper as marking the early high stages of lake Warren. C. Whittlesey, Smithsonian Contributions, vol. xv, 1864, pp. 17-22. E. Andrews, "The North American Lakes considered as Chronometers of Postglacial Time," Trans. Chicago Academy of Sciences, vol. ii. Nearly all the edition of this important paper was consumed in the Chicago fire of 1871. It is quite fully reproduced by James C. Southall in "The Recent Origin of Man," 1875, chapter xxxiii (pp. 435-503, with sections); and in "The Epoch of the Mammoth and the Apparition of Man upon the Earth," 1878, chapter xxii (pp. 348-367, with sections). N. H. Winchell, J. S. Newberry, E. W. Claypole, and G. F. Wright, as before cited. Geol. Survey of Canada, Report of Progress to 1863, pp. 912, 913. Warren Upham, Bulletin Geol. Soc. Am., vol. ii, pp. 258-265; vol. iii, pp. 484-487; Geology of Minnesota, Twenty-second An. Rep., for 1893, as before cited; Am. Geologist, vol. xiv, pp. 62-65, July, 1894.

at 30 feet was formed after that at 15 feet is shown by the occurrence in some places of a peat deposit, described by Andrews and Leverett, which passes underneath the 30 feet beach and is continuous from its upper side down to the lower beach. The peat marks a land surface over which the lake rose to form the middle or third beach, after having stood at the lower or second beach for some time. Still later, however, it probably again stood at the lower level, corresponding to the present watershed in the abandoned outlet. This old channel of outflow, at its summit, as I am informed by Mr. Ossian Guthrie from the canal survey, is now 11 feet above the mean level of lake Michigan, but the surface there is post-glacial silt; at another point, where the channel bed consists of till, and at a third place where the bed is rock, its hight in each case is only eight feet above the present lake, or 590 feet above the sea. The mouth of lake Warren appears to have been at first near Lemont, on the Des Plaines river, about 25 miles from the lake, where the river valley was obstructed by drift which suffered erosion, allowing the mouth of the lake to be transferred gradually upstream, at the same time being lowered to its final position ten miles from the lake shore in Chicago. Epeirogenic movements, between the times of formation of the second and third beaches, slightly lifted the outlet and adjacent portion of the course of the Des Plaines river, as compared with the southern and southwestern part of the lake Michigan basin, causing the old lake to extend a little farther on that side than before. Toward the north and east, however, this change was doubtless more than counteracted by the rapid differential rise of the land.

Fresh-water shells are found abundant in the 15 feet beach at Evanston and elsewhere southward through Chicago. All the species obtained, representing ten or more genera, are still living in this region. Wood of oak and cedar, and the thigh bone of a deer, have been also found in the same beach at Evanston.*

For the distance of about 185 miles from Chicago north to the south end of Green bay, the highest shore of lake Warren appears to be now nearly level, for Mr. Taylor finds evidence of submergence only to a hight of some 20 feet above that part of Green bay and the neighboring lake shore. Thence northward, however, the beach rises about 1.4 feet per mile for 110

*H. M. Bannister, Geology of Illinois, vol. iii, 1868, pp. 241, 242. F. Leverett. "Raised Beaches of Lake Michigan," before cited, p. 169.

miles to Cook's Mill, near the north end of this bay; in 60 miles from that latitude north to Houghton, it has an ascent of 260 feet, or 4⅓ feet per mile; but in about 90 miles onward, across lake Superior to Kaministiquia, where the shore is 455 feet above that lake, the rate of northward ascent is reduced to only a half of a foot per mile,

Along a west to east course, the Nelson beach (named by Taylor in the vicinity of North Bay, lake Nipissing, probably not distinct from the Belmore beach in Ohio and northward to Mackinac island) is 385 feet above lake Superior at Duluth; 410 feet at Houghton, having an eastward ascent of 25 feet in 150 miles; 414 feet at the Sault Ste. Marie, running level for 200 miles east from Houghton; and about 538 feet at the north side of lake Nipissing, or 497 feet above that lake, and 1,140 feet above the sea. In the distance of 220 miles from Sault Ste. Marie to lake Nipissing this beach now shows an ascent of 124 feet, or about seven inches per mile. These figures, with the preceding from Houghton to the north side of lake Superior, justify to a remarkable degree Dr. Lawson's opinion that the ancient shore lines of lake Warren in the Superior basin remain parallel with the water level of to-day. As compared with Chicago, the country enclosing lake Superior has been uplifted 400 to 450 feet; and the greater part of the differential elevation, expressed by tilting, took place upon the west to east belt of the northern peninsula of Michigan.

Three beaches of lake Warren are mapped by Spencer and named the Ridgeway, Arkona, and Forest beaches in Ohio, southeastern Michigan, and the province of Ontario north of lake Erie. These probably represent the three noted at Chicago and about the south part of lake Michigan. Farther north the number of distinct shore lines is much increased. In and near Duluth I find eight beaches referable to lake Warren, the lowest being 50 feet above lake Superior. On northern portions of the lake Superior coast several of these seem, as shown by Lawson's observations with leveling, to be each represented by two or more shores, separated by vertical intervals of 10 feet or more. Most of the northern beaches, it should be remarked, are very feebly developed, even in the most favorable situations for their formation, and are not discernible along the far greater part of the lake borders. During all the time of differential uplifting of the lake Warren basin and sinking of the water surface, whenever the diminishing lacustrine area was nearly unchanged for a few years or

longer, the erosion and deposition effected by the great waves of storms, and the tribute of streams forming deltas, recorded these short lines.*

Lake Algonquin.†—When the glacial melting and retreat at length permitted an outflow from the St. Lawrence basin over a lower pass, which was through central New York to the Mohawk and Hudson, the water surface of the basins of lakes Michigan, Huron, and Superior, fell only some 50 or 75 feet, from the latest and lowest stage of lake Warren to its short-lived successor, lake Algonquin. This lake appears to have been ice-dammed only at low places on its east end, as at or near the heads of the Trent and Mattawa rivers, lying respectively east of lakes Simcoe and Nipissing, where otherwise its waters must have been somewhat further lowered to outflow by these passes. Careful study and comparison of the work of Spencer in tracing the Algonquin beach about the southern part of lake Huron and Georgian bay, and of Taylor in exploration of his "Nipissing beach" from Duluth east along the south coast of lake Superior and the north side of lake Huron and Georgian bay to lake Nipissing, convince me that these beaches were of contemporaneous formation, marking respectively the southern and northern shores of lake Algonquin, and therefore both to be known by the name Algonquin beach of Spencer, according to the law of priority. The earliest and principal stage of lake Algonquin is shown by these beaches to have coincided closely in area with lakes Michigan and Superior, but to have been considerably more extensive eastward than the present lake Huron and Georgian bay. It held a level which now by subsequent differential epeirogenic movements is left probably wholly below the level of lake Michigan by a vertical amount ranging from almost nothing to about 40 feet. Its shores were nearly coincident with the western shore of lake Huron, but eastward they are now elevated mostly 150

*Prof. Spencer, in his latest paper ("A Review of the History of the Great Lakes." Am. Geologist, vol. xiv, pp. 298, 301. Nov., 1894), supposes that an outflow from lakes Superior, Huron, Michigan, and Erie. passed by the way of Chicago to the Des Plaines and Mississippi rivers so lately as about 1,500 years ago, when the Niagara river had cut back its gorge to the Johnson ridge, about a mile north of the present site of the falls. This would have formed a beach 10 to 15 feet above lakes Michigan and Huron, and about 20 to 25 feet above lake Erie, around all their shores; and the absence of such a modern and still horizontal shore line, slightly higher than the present lake levels upon all this large area, forbids an acceptance of this hypothesis.

†J. W. Spencer, "Deformation of the Algonquin Beach, and Birth of Lake Huron." Am. Jour. Sci., III, vol. xli, pp. 12-21, with map, Jan., 1891; and other papers before cited. G. K. Gilbert, F. B. Taylor, and Warren Upham, as before cited for lake Warren. G. F. Wright, Bulletin Geol. Soc. Am., vol. iv, pp. 423-5; with ensuing discussion by Dr. Robert Bell, pp. 425-7.

to 200 feet above that lake and Georgian bay; and in the lake Superior basin they vary from about 50 feet above lake Superior at its mouth, and along its northeastern and northern shores, to 25 feet at Houghton, and to a few feet or none at Duluth.

The Algonquin beach at the south end of lake Huron coincides very closely with the land surface there and with the present St. Clair and Detroit rivers, by which the earliest outflow of the old glacial lake probably passed southward and thence ran east as a glacial River Erie, at first tributary to lake Lundy. As soon as that very briefly existing glacial lake was drained away, the river followed the lowest part of the shallow bed of the present lake Erie along all its extent, which then had an eastward descent of probably 200 feet, allowing no lake or only a very small one to exist in the deepest depression of the basin; and north of Buffalo it coincided with the course of the Niagara river.

Gilbert, Wright, and Spencer, have thought that for a long time the outflow of the three great lakes above lake Erie passed by the way of lake Nipissing to the Mattawa and Ottawa rivers It seems to me far more probable, however, that the epeirogenic uplift of the Nipissing region, which had elevated it already about 400 feet during the existence of lake Warren, continued so fast that both the Trent and Nipissing-Mattawa passes were raised the additional 50 feet needed to place them above the level of lake Algonquin before the glacial retreat uncovered the country east of them so that outlets could be obtained there.

With the continuance of the uplift of the lake Superior basin after the formation of the Algonquin beach, the mouth of lake Superior and the Sault Ste. Marie came into existence; and this movement allowed the lake level at Duluth to fall probably 40 or 50 feet beneath the Algonquin and present shore line. Subsequent differential elevation of the eastern and northern parts of the basin, as compared with Duluth, has again brought the west end of the lake up to the Algonquin shore, but not until the St. Louis river, while the water surface stood considerably lower than now, had deeply eroded its broad channel through the very gently sloping expanse of till from Fond du Lac to the harbor of Duluth and Superior.

The differential uplift of the Algonquin beach, as compared with Chicago and the previous mouth of lake Warren, has been about 60 feet near the mouth of lake Huron and at Duluth;

110 feet at the mouth of lake Superior; 200 feet at lake Nipissing; and 240 to 290 feet at Barrie, Lorneville, and Orillia, on lake Simcoe. A broad lobe of the waning ice-sheet, terminating on the highland area between the south end of Georgian bay and the west end of lake Ontario, appears to have delayed the elevation of that district, so that subsequent to the formation of the Algonquin beach more uplifting took place there than at the north side of Georgian bay and about lake Nipissing. The ascent of the Algonquin beach in nearly 200 miles from the mouth of lake Huron northeasterly to lake Simcoe averages about a foot per mile; and thence in about 135 miles north to lake Nipissing it descends at an average rate of about eight inches per mile.

While the eastern part of the lake Algonquin area was being much uplifted, with the formation of other beaches below the first, probably the southern part of the lake Michigan basin remained with a very slight change of attitude or none, having previously risen to approximately its present hight, which it has since held with little or no change. But the northeastward elevation, raising the country where lake Algonquin and now lake Huron have outflowed, gradually caused the water level at Chicago to rise some 40 feet above its old Algonquin level, which is shown by a sublacustrine terrace formed by the Algonquin erosion and beach accumulation.

On the Saugeen river, Ontario, and near the south end of Georgian bay, fresh-water shells are found in beds belonging to stages of lake Algonquin respectively about 40 and 100 feet below the main and earliest Algonquin beach, or 90 and 78 feet above the present lake and bay.

*Lake Lundy.**—From the Forest beach at Crittenden, Erie county, N. Y., marking the latest level of lake Warren, there is a descent of 125 feet between 860 and 735 feet above the sea to the earliest strand of the glacial lake Lundy, which for a time occupied the northeastern three-fourths of the lake Erie basin. A more conspicuous principal Lundy beach, 30 feet lower, on which is the "ridge road" named Lundy lane, near Niagara Falls, has an eastward ascent of 30 feet in about 40 miles from Font-hill, Ont., to Akron, N. Y., five miles north of Crittenden. Lake Lundy opened through a strait about 30 miles wide into the lake Ontario basin. Its outflow passed eastward, across the country close north of the Finger lakes, to the Mohawk and

* J. W. Spencer, "Deformation of the Lundy Beach and Birth of Lake Erie," Am. Jour. Sci., III, vol. xlvii, pp. 207-211, with map, March, 1894.

Hudson valleys, still partly filled by the receding ice-sheet and permitting a series of mouths of lake Lundy to be found at successively lower levels, until as the ice-border withdrew the water soon sank to the lowest point of the Ontario-Mohawk watershed at Rome, N. Y., where its level long remained, forming the Iroquois beach. One of the stages of the sinking lake Lundy or incipient lake Iroquois, probably nearly midway in altitude between the Lundy and Iroquois beaches, I find to be indicated by my studies of eskers in Rochester and Pittsford, N. Y.*

Lake Iroquois.†—This glacial lake, overflowing at Rome to the Mohawk and Hudson, occupied less area in the west part of the lake Ontario basin during its earliest stage than during the later and probably longer enduring lake stage by which the high Iroquois beach in that region was formed. Previous to the date of the western development of the Iroquois beach, the early water level stood at one time only a little higher than the present lake Ontario at Toronto and Scarboro Hights, 6 to 15 miles east of Toronto, as compared with the altitude, doubtless absolutely lower than now with regard to the sea, which the land then held in that part of the lake basin. This is shown by the occurrence of fossil fresh-water mollusks of fourteen species, and wood of ash, oak, and American yew, in beds at Toronto, described by Coleman, which now are 33 to 51 feet above lake Ontario, or 280 to 298 feet above the sea. All the mollusk species are now living; but four are restricted, so far as known, to waters tributary to the Mississippi. A boulder-bearing surface deposit above these beds proves that the front of the ice-sheet was not far distant; but the climatic conditions of that time, clearly indicated by the fauna and flora, were as mild as now. There next ensued, probably, a gradual rise of the lake, due to an uplifting of the country about its outlet at Rome, until it stood at the level of the well

*Proceedings of the Rochester Academy of Science, vol. ii, pp. 196-198, Jan., 1893.

†J. W. Spencer, "The Deformation of the Iroquois Beach and Birth of Lake Ontario," Am. Jour. Sci., III. vol. xl, pp. 443-451, with map, Dec., 1890; and papers previously cited. Thomas Roy (in paper by Sir Charles Lyell), Proceedings Geol. Soc., London, vol. ii, 1837, pp. 537, 538. Sir Charles Lyell, Travels in N. A., in 1841-42, vol. ii, chapter xx. E. J. Chapman, Canadian Journal, new series, vol. vi, 1861, pp. 221-229, and 497, 498. Sandford Fleming, Can. Jour., same vol. vi, pp. 247-253. George J. Hinde, Can. Jour., vol. xv, 1877, pp. 388-413. A. P. Coleman, Am. Geologist, vol. xiii, pp. 85-95, Feb., 1894. Geol. Survey of Canada, Report of Progress to 1863, pp. 912, 913. James Hall, Geology of New York, Part iv, 1843, pp. 348-351. Baron Gerard de Geer, "On Pleistocene Changes of Level in eastern North America," Proc. Boston Soc. Nat. Hist., vol. xxv, 1892, pp. 454-477, with map; also (excepting the map) in Am. Geologist, vol. xi, pp. 22-44, Jan., 1893. G. K. Gilbert, F. B. Taylor, E. W. Claypole, G. F. Wright, and Warren Upham, as cited for lakes Warren and Algonquin.

defined Iroquois beach, which has a hight at Toronto of about 200 feet above lake Ontario. Thick fossiliferous delta deposits had been, meanwhile, brought into the north edge of the lake at Toronto and several miles eastward along the lake-cliff section of Scarboro Hights, described by Hinde; and repeated re-advances of the ice-front, one during, and another after, the delta accumulation, formed, at the locality last noted, two deposits of till or boulder-clay.

In a limited sense the Toronto and Scarboro fossils may be called Interglacial, since they lie between deposits of glacial drift; but they seem better referred to moderate oscillations of the ice boundary than to the distinct glacial epochs which Coleman and Hinde infer from them. Both these beds and the richly fossiliferous Leda clays, which last overlie the latest glacial drift in the St. Lawrence, Ottawa, and Champlain valleys, may be referred to the closing stage or Champlain epoch of the Ice age; and they both testify, like the partially forest-covered Malaspina ice-sheet in Alaska, of the close sequence of a warm climate, with luxuriant plant and animal life, during and immediately after the recession of the ice-sheet. The transition from the Glacial to the Champlain climate seems readily explained by the epeirogenic depression which ended the Glacial period.*

The hight of lake Ontario is 247 feet; and that of the old Iroquois outlet crossing the water-shed at Rome is 440 feet. above the sea level. Thence the Iroquois beach in its course northward adjacent to the eastern end of lake Ontario has a gradual ascent, determined from leveling by Mr. G. K. Gilbert and the present writer. of about five feet per mile along a distance of 55 miles to the latitude of Watertown, where the highest beach is 730 feet above the sea, showing that a differential uplift of about 290 feet has taken place, in comparison with the Rome outlet. From Rome westward to Rochester. the beach has nearly the same hight with the outlet; but farther westward it descends to 385 feet above the sea at Lewiston and 363 feet at Hamilton, at the western end of lake Ontario. Continuing along the beach north of the lake, the same elevation as the Rome outlet is reached near Toronto. and thence east-northeastward an uplift is found, according to Spencer's leveling, similar to that before described east of the

*J. D. Dana, Trans. Conn. Acad. of Arts and Sciences. vol. ii, 1870, p. 67; Am. Jour. Sci., III, vol. x, pp. 168-183, Sept., 1875. Warren Upham, Glacialists' Magazine, vol. i. pp 236-240, June, 1894.

lake, its amount near Trenton and Belleville above Rome being about 240 feet. It is to be added that northward from Rome the Iroquois beach becomes divided into a series of distinct beaches, marking stages in the northeastward rise of the land and having near Watertown a vertical range of 80 feet below the highest and oldest, which was before noted; and that westward a similar series of strand lines also lies below the highest, likewise before noted, which there, however, contrary to the order northeastward, was the newest. The highest beach near Watertown was probably contemporaneous with the fossiliferous beds of Toronto; some of the intermediate northeastern beaches corresponded to the delta deposits of Scarboro; and the lowest northeastward lake level was continuous with the highest at Toronto, Hamilton, Lewiston, and east to Rome.

Between lakes Warren and Lundy the old water level near the west end of lake Ontario fell 125 feet, minus some amount to be subtracted for the progressing northeastward elevation of the land. The two Lundy shores are 30 feet apart vertically. From the lower and main Lundy beach the water fell about 480 feet to the earliest stage of lake Iroquois when the Toronto fossil shells lived in the edge of that lake, excepting that here again some undetermined amount must be subtracted to compensate the concurrent rise of the land. Adding these vertical intervals together, we have 635 feet, which probably may be reduced 100 feet, more or less. for the effects of the accompanying epeirogenic uplift. We have left some 500 or 550 feet, to be subtracted from the altitude of the old Chicago outlet of lake Warren, believed to have been then approximately as now, 590 feet above the sea, to give the earliest altitude of the Rome outlet. It thus appears, as I concluded from a similar computation four years ago, that the Rome outlet was at first only 50 or 100 feet above the sea level.* It was gradually uplifted, participating in the differential rise of the whole Ontario basin, to about 300 feet above the sea while the outflow continued here, and to probably 350 feet or more, lacking less than 100 feet of its present hight, by the time when the much farther retreat of the ice permitted the extension of the sea to Ogdensburgh and Brockville, on the St. Lawrence river near the mouth of lake Ontario. Intermediate between lake Iroquois and the Champlain incursion of the sea, the glacial lake St. Lawrence, into which lake Iroquois was merged by the retreat

* Bulletin Geol. Soc. Am., vol. II, pp. 260-262.

of the ice-sheet from the northern side of the Adirondacks. filled the lake Ontario basin for a considerable time at levels below the Iroquois beaches.

As the area of lake Warren was being differentially much elevated during the earlier existence of that lake, and as the area of lake Algonquin was similarly uplifted in part or wholly contemporaneously with the Iroquois basin, so this region was being rapidly raised and tilted upward to the north and east while the lake level, held constantly without important downward cutting at the Rome outlet, inscribed many shore lines on the slowly moving land. All the movement throughout the whole region probably was upward; but the position of Rome. and its greater rise than western parts of the basin during the existence of lake Iroquois, caused the old beaches westward to have now declining gradients.

*Lake Hudson-Champlain.**—The absence of marine fossils in beds overlying the glacial drift on the shores of southern New England, Long Island, and New Jersey, and the water-courses which extend from the terminal moraine on Long Island southward across the adjacent modified drift plain and continue beneath the sea level of the Great South bay and other bays between the shore and its bordering long beaches, prove that this coast stood higher than now when the ice-sheet extended to its farthest limit. A measure of this elevation of the seaboard in the vicinity of New York during the Champlain epoch is supplied, as I believe, by the shallow submarine channel of the Hudson, which has been traced by the soundings of the U. S. Coast Survey from about 12 miles off Sandy Hook to a distance of about 90 miles southeastward. This submerged channel, lying between the present mouth of the Hudson and the very deep submarine fjord of this river, ranges from 10 to 15 fathoms in depth, with an average width of 1¼ miles, along its extent of 80 miles. the depth being measured from the top of its banks, which, with the adjacent sea-bed, are covered by 15 to 40 fathoms of water, increasing southeastward with the slope of this margin of the continenal plateau. During the whole or a considerable part of the time of the glacial lake Iroquois, this area stretching 100 miles southeastward from New York

* Warren Upham. Bulletin Geol. Soc. Am., vol. i, p. 566; vol. ii, p. 265; vol. iii. pp 484-487 (first using this name). C. H. Hitchcock, Geology of Vermont, 1861, vol. i, pp. 93-167, with map. J. S. Newberry, Pop. Sci. Monthly, vol. xiii, 1879, pp. 641-660. F. J. H. Merrill. Am. Jour. Sci.. III, vol. xli, pp. 460-466, June, 1891. W. M. Davis, Proc. Boston Soc. Nat. Hist., vol. xxv, 1891, pp. 318-334. S. Prentiss Baldwin, "Pleistocene History of the Champlain Valley," Am. Geologist, vol. xiii, pp. 170-184. with map. March, 1894. Baron de Geer, as cited for lake Iroquois.

was probably a land surface, across which the Hudson flowed with a slight descent to the sea. But northward from the present mouth of the Hudson the land at that time stood lower than now; and the amount of its depression, beginning near the city of New York and increasing from south to north, as shown by terraces and deltas of the glacial lake Hudson-Champlain, which were formed before this long and narrow lake became merged in the glacial lake St. Lawrence, was nearly 180 feet at West Point, 275 feet at Catskill, and 340 feet at Albany and Schenectady. From these figures, however, we must subtract the amount of descent of the Hudson river, which in its channel outside the present harbor of New York may probably have been once 50 or 60 feet in its length of about 100 miles.

Before the time of disappearance of the ice-barrier from the St. Lawrence valley at Quebec, the descent of the Hudson river beyond New York city may have diminished, or the seaboard at New York may have sunk so as to bring the shore line nearly to its present position; but the Hudson valley meanwhile had been uplifted, so that the outflow from the lake St. Lawrence crossed the low divide, now about 150 feet above the sea, between lake Champlain and the Hudson. This is known by the extension of fossiliferous marine deposits along the lake Champlain basin nearly to its southern end, while they are wholly wanting along all the Hudson valley. Indeed, the outflowing river from lakes Iroquois, Hudson-Champlain, and St. Lawrence, or the Hudson during the Postglacial period, channeled the lower part of this valley to a depth of about 100 feet below the present sea level, proving that the land there, as Merrill points out, stood so much higher than now at some time after the ice retreated.

According to the observations of Davis, Baldwin, and Baron de Geer, the highest shore line of the lake Hudson-Champlain is now elevated to about 275 feet above the sea at Catskill, N. Y.; 550 feet in Chesterfield, N. Y., on the west side of lake Champlain opposite to Burlington; and 658 feet at St. Albans, Vt. Assuming that the mouth of the lake, near New York City, was 50 feet above the sea, the differential northward uplift of the originally level shore has been at the rate of about two feet per mile for the 100 miles from the present mouth of the Hudson to Catskill; 1.7 feet per mile for the next 160 miles north to Chesterfield; and about three and a half feet per mile in the next 30 miles north-northeastward to St. Albans. Perhaps a

higher beach may exist in Chesterfield, which would bring these gradients nearer to uniformity. The series noted there by Baldwin comprises eight beaches referable to the successive water levels of lake Hudson-Champlain, lake St. Lawrence, and the sea in the Champlain basin, their hights above the sea level of to-day being 550 feet, 530, 470, 423, 386, 365, 335, and 290 feet. The mean level of lake Champlain is 97 feet above the sea, and its maximum depth 402 feet. The lower four of these beaches belonged to the Champlain arm of the enlarged Gulf of St. Lawrence, as shown by the hight of its sand deltas and associated fossiliferous clays; but the higher four represent stages of the lakes Hudson-Champlain and St. Lawrence. These shore lines, like those of the glacial lakes farther west to lake Agassiz, were probably formed during times of rest or slackening in the somewhat intermittent epeirogenic elevation of the land.

*Lake St. Lawrence.**—The records of the Glacial and Champlain epochs in the St. Lawrence valley have been most fully studied during many years by Sir William Dawson, to whose work chiefly we are indebted for detailed descriptions of the evidences of the marine submergence of that region to a maximum hight at Montreal somewhat exceeding 500 feet above the present sea level. Earlier than that time of occupation of the depressed broad valley by the sea, it was filled from lake Ontario to near Quebec, by a great glacial lake, held on its northeast side by the receding continental ice-sheet. The directions of the glacial striæ and transportation of the drift in the St. Lawrence valley, running southwestward at Montreal and onward to the great lakes, but eastward from Quebec down the shores of the Gulf of St. Lawrence, and southeast across Nova Scotia and New Brunswick, show that the latest remnant of the ice barrier blockading this valley was melted away in the neighborhood of Quebec, then admitting the sea to a large low region westward. Until this barrier was removed, a glacial lake, which here for convenience of description and citation is designated as the lake St. Lawrence, dating from the con-

---

*Sir J. William Dawson, the Canadian Ice Age (Montreal, 1893), pp. 301, with maps and sections, views of scenery, and nine plates of Pleistocene fossils. This volume sums up the author's work since 1855 on the glacial drift and associated lacustrine and Champlain marine formations of the St. Lawrence valley, embodying the studies which had been published in many papers in the "Canadian Naturalist and Geologist" and elsewhere. He had given a similar summary in a pamphlet of 112 pages, "Notes on the Post-pliocene of Canada," in 1872. J. W. Spencer, G. K. Gilbert, Baron de Geer, S. Prentiss Baldwin, and Warren Upham, as before cited for lakes Warren, Algonquin, Iroquois, and Hudson-Champlain.

fluence of lakes Iroquois and Hudson-Champlain and growing northward and eastward, spread over the Ottawa valley probably to the mouth of the Mattawa, and down the St. Lawrence, as fast as the ice-front was melted back.

When lake Iroquois ceased to outflow at Rome and, after intervening stages of outlets existing for a short time at successively lower levels north of the Adirondacks, began to occupy the Champlain basin and the St. Lawrence valley northward, changing thus to the lake St. Lawrence, its surface fell by these stages about 250 feet to the glacial lake Hudson-Champlain, which had doubtless reached northward nearly to the St. Lawrence. After this reduction of the water body in the Ontario basin, it still had a depth of about 150 feet over the present mouth of lake Ontario, as shown by a beach traced by Gilbert, which thence rises northeastward but declines toward the south and southwest. Its plane, which is nearly parallel with the higher Iroquois beaches, sinks to the present lake level near Oswego, N. Y. Farther southwestward the shore of the glacial lake at this lower stage has been since submerged by lake Ontario. The Niagara river was then longer than now, and the lower part of its extent has become covered by the present lake. From the time of the union of lakes Iroquois and Hudson-Champlain, a strait, at first about 150 feet deep, but later probably diminished on account of the rise of the land to the depth of about 50 feet, joined the broad expanse of water in the Ontario basin with the larger expanse in the St. Lawrence and Ottawa valleys and the basin of lake Champlain. At the subsequent time of ingress of the sea past Quebec the level of lake St. Lawrence fell probably 50 feet or less to the ocean level. The place of the glacial lake so far westward as the Thousand Islands was then taken by the sea, with the marine fauna which is preserved in the Leda clays and Saxicava sands.

The Champlain Marine Submergence.

That the land northward from Boston was lower than now while the ice-sheet was being melted away, is proved by the occurrence of fossil mollusks of far northern range, including *Yoldia* (*Leda*) *arctica* Gray, which is now found living only in the Arctic seas, preferring localities which receive muddy streams from existing glaciers and from the Greenland ice-sheet. This species is plentiful in the stratified clays resting on the till in the St. Lawrence valley and in New Brunswick

and Maine, extending southward to Portsmouth, N. H. But it is known that the land was elevated from this depression to about its present hight before the sea here became warm and the southern mollusks, which exist as colonies in the Gulf of St. Lawrence, migrated thither, for these southern species are not included in the extensive lists of the fossil fauna found in the beds overlying the till.

In the St. Lawrence basin these marine deposits reach to the southern end of lake Champlain, to Ogdensburgh and Brockville, and at least to Pembroke and Allumette island, in the Ottawa river, about 75 miles above the city of Ottawa. The isthmus of Chiegnecto, connecting Nova Scotia with New Brunswick, was submerged, and the sea extended 50 to 100 miles up the valleys of the chief rivers of Maine and New Brunswick. The uplift of this region from the Champlain sea level was 10 to 25 feet in the vicinity of Boston and northeastward to Cape Ann; about 150 feet near Portsmouth, N. H.; from 150 to about 300 feet along the coast of Maine and southern New Brunswick; about 40 feet on the northwestern shore of Nova Scotia; thence increasing westward to 200 feet in the Bay of Chaleurs, 375 feet in the St. Lawrence valley opposite the Saguenay, and about 560 feet at Montreal; 150 to 400 or 500 feet, increasing from south to north, along the basin of lake Champlain; about 275 feet at Ogdensburgh, and 450 feet near the city of Ottawa. The differential elevation was practically completed, as we have seen from the boreal character of the Champlain marine molluscan fauna, shortly after the departure of the ice-sheet. With the areas of the glacial lakes Agassiz, Warren, and Iroquois, in the interior of the continent, this coastal region gives testimony of a wave-like epeirogenic elevation of the formerly ice-laden portion of the earth's crust, proportionate with the glacial melting and closely following the retreat of the ice from its boundaries of greatest extent inward to the areas on which its waning remnants lingered the latest.

On the Green Mountains of Vermont, the White Mountains region, and indeed probably over a large part of New England, a tract of the departing ice-sheet remained after the access of the sea to the St. Lawrence basin left the New England ice as an isolated mass. This is known by the large tribute of stratified drift quickly brought by streams from the melting ice of the Green Mountains area and deposited as gravel and sand deltas and offshore clays of the Winooski, La Moille, and Mis-

sisquoi rivers, described by Hitchcock and Baldwin, in the east border of the Champlain arm of the sea. On the west, too, a considerable remnant of the ice-sheet seems to have remained unmelted until this time on the Adirondacks, and to have likewise supplied the deltas and marine clays of the Au Sable, Saranac, and Chazy rivers in New York. Deflections of glacial striation down the valleys, with corresponding drift transportation and formation of local moraines across some of the mountain valleys, have been recorded by Hitchcock, Stone, and others, in Vermont and New Hampshire; but the time allowed for such glacial action, under the warm Champlain climate, was very short. The earlier melting of the ice along the St. Lawrence valley than on these mountain tracts was due on one side to the laving action of the waves of lakes Iroquois and St. Lawrence, and on the other side to the washing of the ice-cliffs by the fast encroaching sea in the Gulf of St. Lawrence, until at last near Quebec the barrier was severed.

From the Champlain submergence our Atlantic coast was raised somewhat higher than now; and its latest movement from New Jersey to southern Greenland has been a moderate depression. The vertical amount of this postglacial elevation above the present hight, and of the recent subsidence, on all the coast of New Jersey, New England, and the eastern provinces of Canada, is known to have ranged from 10 feet to a maximum of at least 80 feet at the head of the Bay of Fundy, as is attested in many places by stumps of forests, rooted where they grew, and by peat beds now submerged by the sea. As in Scandinavia, the restoration of isostatic equilibrium is attended by minor oscillations, the conditions requisite for repose having been overpassed by the early re-elevation of outer portions of each of these great glaciated areas. The close of the Ice age was not long ago, geologically speaking, for equilibrium of the disturbed areas has not yet been restored.

Measurement of the Postglacial Period by the Recession of Niagara Falls.

Gilbert has recently expressed his doubt that the past rate of erosion of the gorge below the receding falls of Niagara can be so compared with the present rate as to afford any approximate measure of the time which has elapsed since the Ice age.* His first study of this question† gave about 7,000 years for the erosion of the Niagara gorge, if it had proceeded

*Nature, vol. 50, p. 53, May 17, 1894.

†Proc. Am. Assoc. for Adv. of Science, vol. xxxv. for 1886, pp. 222, 223.

with an average rate like the present. As this erosion began at the time of retreat of the ice-sheet from that area and has been in progress during all the subsequent time, it has been regarded as a geologic chronometer, like the similar erosion of the gorge below the falls of St. Anthony, from which Prof. N. H. Winchell had previously computed the length of the Post-glacial period in Minnesota to be about 7,800 years. On the other hand, Spencer gives the results of his computation of the duration of the Niagara falls and gorge as about 32,000 years.*

The largest element of uncertainty (as hitherto supposed) in the estimate drawn from the rate of recession of Niagara falls is shown by Gilbert's second and more full discussion,† to consist in the probability or possibility that for some considerable time, next following the melting away of the ice upon the area crossed by the Niagara river, the outlet of lakes Superior, Michigan, and Huron, may have passed to the St. Lawrence by a more northern course, flowing across the present watershed east of lake Nipissing to the Mattawa and Ottawa rivers. The Niagara would then have been a small river, being left with only a small area of drainage and consequently capable of only slow erosion of its gorge. This condition Spencer supposes to have lasted no less than 24,000 years, or three-fourths of the time which he allows for the whole of the gorge erosion. Against this hypothesis, the investigation here presented seems to bring important and decisive objections.

First we must note that the views held by Spencer and Taylor, that the high shore lines around the great Laurentian lakes are of marine formation, is inconsistent with the total absence of marine fossiliferous beds overlying the glacial drift throughout the basins of these lakes. Instead, fresh-water molluscan shells are found in the beaches and offshore deposits of lakes Warren, Algonquin, and Iroquois, as noticed in these pages. ‡ So far as the sea did extend, after the farther recession of the ice-sheets permitted it to come into the St. Lawrence and Ottawa valleys and into the basin of lake Champlain, marine fossils abound; but none are found above the Thousand Islands, which lie in the St. Lawrence at the mouth of lake Ontario. We may, therefore, confidently accept the Niagara

* Am. Geologist, vol. xiv, pp. 298-301, with longitudinal section of the Niagara gorge, Nov., 1894; Am. Jour. Sci, III, vol. xlviii, pp. 455-472, with maps and sections, Dec., 1894.

† "History of the Niagara River," before cited with reference to lake Warren.

‡ Fresh-water shells are also found in the beaches of lake Agassiz (Geol. and Nat. Hist. Survey of Canada, Ann. Rep., new series, vol. iv, for 1888-89, p. 49 E).

gorge as a measure of all the time since that area was uncovered from the ice-sheet.

The foregoing review of the departure of the ice-sheet from the St. Lawrence basin, and of the accompanying wave-like uplift, shows clearly that New York and New England were the last portions of the United States, at least eastward from the Rocky mountains, to be uncovered from the fast waning continental glacier. When lake Warren attained its greatest extent, the ice-sheet had melted off from all the northern United States west of lake Nipissing and Buffalo, N. Y.; but yet, to hold this glacial lake on the east, it remained unmelted upon the Niagara and lake Ontario or Iroquois area. Thus we see that all the moraines within the limits of the United States west of the great angle of the drift boundary near Salamanca, in southwestern New York,* are somewhat older than the moraines east of that angle, in New York, Pennsylvania, New Jersey, Long Island, and New England. The difference in age, however, between the western and eastern moraines and drift was, perhaps, no more than 500 to 1,000 years, as we may infer from the rate of retreat of the portion of the ice-front forming the northern barrier of lake Agassiz.

This view of the order of going of the ice-sheet finds meteorological explanation as follows: Doubtless the prevailing course of storms during the Glacial and Champlain epochs, as at the present time, was from west to east and northeast. With the restoration of a temperate climate by the subsidence of the land to its present hight or lower, the sunshine and rains began to melt the ice away. Its border in general retreated and became steeper, but with interruptions, ranging in length from decades to centuries, when the snow accumulation and ice outflow caused important extensions of the glaciation. The warm air currents, bringing rain storms and therefore rapidly melting the front of the ice where they first swept over it at the west, would, however, be chilled as they passed onward, giving principally snowfall on more eastern parts of the ice margin. The western ice-melting also contributed much to the supply of moisture for this snowfall from the eastwardly moving storms. Hence, the eastern great ice-lobe, from Salamanca to Long Island, Cape Cod, and the Gulf of Maine, would be fed and fattened to be thick and spread in some places

* Consult Prof. Chamberlin's maps of the glaciated areas of the United States, U. S. Geol. Survey, Third Annual Report, Plates xxviii and xxxiii; Seventh An. Rep., Plate viii.

even beyond its previous limits, while all of the ice-sheet farther west in the United States was being melted away. *

Another unexpected conclusion, relative to the volume of the Niagara river while the ice-sheet was departing, is brought by our consideration of the uplift of the northern side of the glacial lake Warren, which along its extent of 600 miles from west to east was rapidly raised in general about 350 to 400 feet, as compared with the Chicago outlet, before the date of the Algonquin beach. In the vicinity of lake Nipissing this beach is 100 feet above that lake, or 743 feet above the sea, being so high, 50 feet upon a width of more than a mile, above the watershed east of the lake leading to the Mattawa and Ottawa rivers, that I cannot believe a river of such depth and width to have there outflowed. Instead, I think that the ice-sheet then still remained as a barrier upon the Mattawa and Ottawa areas; and that the earliest outflow from lake Algonquin went southward by way of the present St. Clair and Detroit rivers and thence east along the bed of lake Erie, as soon as the glacial lake Lundy was drained away, to the incipient Niagara and lake Iroquois. Eight-ninths of all the uplifting of the Nipissing area which carried its watershed above the hight at which it could be an outlet of lake Algonquin had taken place before the Niagara river and lake Iroquois began to exist. Later, while yet the ice was a barrier on the Mattawa area, I believe that the continuation of that uplift fully raised the Nipissing-Mattawa divide above lake Algonquin, for meanwhile the lake Iroquois area was undergoing a large differential uplift of increasing amount from south to north and from west to east. Further evidence that the ice border remained upon the high area between lake Ontario and Georgian bay, turning the waters of lake Algonquin southward and eastward to the Niagara river, until lake Iroquois began to exist with a level in its western part nearly like that of the present lake Ontario, is afforded, as previously shown, by the alternating fossiliferous beds and till deposits of Toronto and Scarboro. The Niagara river and falls thus appear to have had a volume equal to the present during their entire history. If there was any time of diversion of the waters of the upper Laurentian lakes to the Mattawa valley, it was of very brief duration, oc-

* On a smaller scale, during the melting of the ice-sheet in Minnesota, important snow accumulation on the east side of the Minnesota ice-lobe caused its extension while its western side was retreating, as noted, with explanation partly as here given, in Proc. Am. Assoc. for Adv. Science, vol. xxxii, for 1883, pp. 231-234, and Geology of Minnesota, Final Report, vol. ii, pp. 254-256, 409-413.

curring after some longer time of southward flow through the lake Erie basin, and would require only an insignificant addition to the estimate of 7,000 years, as given by Gilbert in 1886, for the duration of the Niagara river and of the Postglacial period.*

The great depth of the Niagara river (having a maximum sounding of 185 feet) at the foot of the falls, and for nearly two miles to the head of the Whirlpool rapids, has been regarded by Gilbert as a corroboration of the hypothesis that the volume of the river was for a long time greatly diminished by a Mattawa outlet from the upper lakes.† The deep excavation below the river level in the more recently eroded part of the Niagara gorge near the falls, analogous to pot-hole erosion, he attributes to a probably larger volume of the river than that which previously formed the shallower and longer portion of the gorge, excepting only at the Whirlpool, where the postglacial gorge coincides with one of preglacial age.‡ The greater thickness of the Niagara limestone, however, may probably account chiefly, as I think, for the deeper excavation by the cataract now than during the early part of its recession. Large blocks of this limestone doubtless act as pestles performing the very deep erosion under the impact of the falling water (an explanation suggested by McGee and published by Gilbert); and the much jointed superficial portion of the limestone may be less serviceable for this work than the deeper beds which were reached along this upper part of the gorge.

Relation of the Champlain Epoch to the Quaternary Era.

The duration of lake Agassiz, probably about 1,000 years, as estimated from the total wave erosion and resulting accumulation of beach gravel and sand on its shores, in comparison with those of lake Michigan during all the time since the recession of the ice-sheet,§ well confirms the earlier conclusion by Dana, from his studies of the valley drift along the river courses of

*Andrew M. Hansen (in the Journal of Geology, vol. ii, p. 142, Feb.-March, 1894) notes the approximate concurrence of about thirty independent measurements and estimates of the length of the Postglacial period which have been made in North America and Europe, all coming within the limits of 5,000 and 12,000 years.

†International Congress of Geologists, Report of the Fifth Session, Washington, 1891 (published 1893), pp. 455-458, with map.

‡Julius Pohlman has written on the preglacial erosion along the course of the Niagara, in Proc. A. A. A. S., vol. xxxv, for 1886, pp. 221, 222.

§Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, vol. iv. for 1888-89, pp. 50, 51 E.

southern New England, that the retreat of the ice and deposition of its drift were very rapid. On the intervening area of the great Laurentian lakes all the observations here brought into correlation and historic sequence give similar testimony of the geologic brevity of the Champlain epoch. The moderate re-elevation from the Champlain depression was mostly accomplished by an epeirogenic movement advancing like a wave closely in company with the glacial melting and retreat; and both appear to have occupied no more than 4,000 or 5,000 years.

Accepting the estimate that the dates of the retreat of the ice-border past the falls of St. Anthony and Niagara falls were respectively about 8,000 and 7,000 years ago, we may well refer all the final melting of the ice-sheet upon the northern United States and British America, except the existing glaciers of the Cordilleran mountain belt and St. Elias region, to a Champlain epoch from 10,000 to 5,000 years ago. This includes the retreat of the ice from its late southern limits to the Altamont or outermost moraine, with the deposition of the loess and the subsequent uplifting of the Wisconsin driftless area and of the greater part of the upper Mississippi and Missouri region, probably occupying 2,000 years, more or less; the further recession during the existence of lake Agassiz and the glacial lakes of the St. Lawrence basin, with the formation of the many moraines traced across the northern states and some southern parts of Canada, probably 1,500 or 2,000 years; and the melting away of the lingering remnants of the ice-sheet upon Labrador and the country northwest of Hudson bay, perhaps 1,000 or 1,500 years. The northward differential uplifting of the area of lakes Agassiz, Warren, Iroquois, and St. Lawrence, took place very rapidly, the maximum epeirogenic movement upward being apparently from a half of a foot to one foot or more each year during several centuries, first on the southern and southwestern portion of the uplifted region, and thence proceeding to the north and northeast. The uplift was nearly proportional with the removal of the ice weight, and was doubtless due to inflow of the plastic or molten interior of the earth beneath the buoyant crust.

How long a time was needed for the great subsidence introducing the Champlain epoch, it will be more difficult to estimate. Perhaps it may have taken as long as the departure of the ice-sheet and the re-elevation, or it may have required twice that time, being thus some 5,000 to 10,000 years. This

was a Late Glacial movement, leading to the end of the Ice age.

The earlier and probably longer part of the Glacial period, while the land had its great altitude causing the snow and ice accumulation on the drift-bearing areas, but with considerable secular climatic fluctuations and therefore retreats and re-advances of the ice-front, may well have included the formation of the early till in Illinois, Indiana, and Ohio, on which Leverett finds a soil and leached subsoil, comparable in thickness with those of the present surface, yet buried under thick deposits of later drift.* To the same time we may also refer the deposition of the flood-plain of glacial gravel and sand whose remnants form the surface of the highest terraces along the upper part of the Ohio river.† Again, in northwestern Illinois, the rock gorges studied by Hershey‡ suggest, like the oxidation, leaching, and soil formation of the early till, and like the great amounts of fluvial sedimentation and subsequent erosion in the Ohio valley, that the Glacial period in the United States was long as measured by years, though short in comparison with all other geologic periods, excepting the Post-glacial. Even with the high altitude favoring powerful stream erosion of the gorges and of the valley drift, the work done indicates probably a duration of the ice-sheet through 30,000 years, more or less, before the subsidence of the land began.

For the early Quaternary time of great elevation, preceding and bringing on the Ice age, we have an estimate of 60,000 to 120,000 years, drawn from the probable rate of deposition of the Lafayette formation in the lower Mississippi valley, and from the ensuing deep erosion of the Lafayette and underlying strata, immediately preceding the ice accumulation and doubtless in part contemporaneous with it.§

These estimates give for the whole Quaternary era some 100,000 or 150,000 years, placing its beginning ten or fifteen times as long ago as that of the Champlain epoch. The Tertiary era appears by the changes of its marine molluscan faunas to have been vastly longer, having comprised perhaps between two and four million years, of which the Pliocene period would be a sixth or eighth part, thus exceeding the

*Proceedings of the Boston Society of Natural History, vol. xxiv, pp. 455-459, Jan. 1, 1890.

†Chamberlin and Leverett, Am. Jour. Sci., III, vol. xlvii, pp. 247-283, with maps and profiles, April, 1894.

‡Am. Geologist, vol. xii, pp. 314-323, Nov., 1893.

§Bulletin, Geol. Soc. Am., vol. v, for 1893, pp. 96-100.

whole of the ensuing era of great epeirogenic movements and resulting glaciation.

Divisions of Quaternary Time.*

The following table of the several divisions, periods, and epochs of Quaternary time, showing their relationship with the Champlain epoch, which has been reviewed for the region of the Laurentian lakes and river St. Lawrence in this paper, is arranged in the descending stratigraphic order of their geologic formations:

Psychozoic division	Recent period	Recent or Present epoch.
		Terrace epoch.
Pleistocene division	Glacial period	Champlain epoch.
		Glacial epoch.
	Lafayette period	Epoch of great elevation and erosion.
		Lafayette epoch.

Seeking to subdivide the Glacial period or Ice age with reference to its dynamic causes and secular fluctuations in climatic conditions, we find, first, a long epoch of general snow and ice accumulation. In its early part the growth of the ice-sheet was interrupted, at least locally and temporarily, by moderate oscillations of its boundary, as shown by layers of lignite between deposits of till observed by Dr. Robert Bell on branches of the Moose and Albany rivers tributary to the southwest side of James bay.† Later, after the ice-sheet attained its maximum stage in the Mississippi basin, reaching south to northeastern Kansas, central Missouri, and southern Illinois, this epoch included a long interval of extensive retreat of that part of the ice-sheet, followed by renewal of its growth until it again reached far south toward its former limits. This part of the Ice age is well denominated, from its envelopment of the land by ice-sheets, the Glacial epoch. Its chief cause I think to have been uplifts of the glaciated regions thousands of feet above their present hight.

Forest beds and other fossiliferous deposits of the interglacial stage in this epoch are found frequently, and on some large tracts almost continuously, occurring between deposits of the till or glacial drift penetrated by wells, from southwestern Ohio, through Indiana and Illinois, to northeastern Iowa and

*More ample discussion of these time divisions is presented in the Am. Naturalist, vol. xxviii, pp. 979-988, Dec., 1894.

†Geol. Survey of Canada, Report of Progress for 1877-78, p. 4 C; and Annual Report, new series, vol. ii, 1886, p. 38 G.

to Mower county in southern Minnesota.* Less frequent, but still sometimes occupying considerable tracts as shown by several wells near together, these interglacial beds are recorded by my notes of wells in Lyon, Renville, and McLeod counties, Minn., 60 to 90 miles north from the south line of this state. More rare instances of their observation are noted as far north as in Mitchell township, Wilkin county, and Barnesville in the south edge of Clay county, Minn.; and these most northern localities are situated within the area of the glacial lake Agassiz, respectively about 100 feet and 75 feet below its highest and earliest or Herman beach. If the altitude and slopes of the land had been then the same as now, an interglacial lake held by the barrier of the receding ice-sheet must have forbidden the growth of forests or formation of swamp deposits there until the outlet was deeply eroded or much farther glacial recession permitted that lake to be drained away northward. Under those conditions the growth of an interglacial forest at Barnesville would imply probably three to six times more glacial melting and recession than otherwise would suffice to account for the most northern of these observed interglacial deposits. It therefore seems to me more likely that during this glacial retreat the present basin of the Red river of the North, which was later occupied by lake Agassiz, had a considerably greater altitude than now, retaining a part, probably a large part, of its preglacial elevation, and that it was thus a land surface with southward descent and free drainage along the Minnesota river valley to the Mississippi. The recession of the ice-sheet, before its renewed growth, may then have reached only to the southern part of the Red river valley, instead of the great farther distance to Hudson bay which I formerly supposed in writing of these interglacial beds in Minnesota.†

The erosion of numerous and large interglacial stream courses in the early drift sheet of southern Minnesota and northern Iowa, including the Minnesota river valley and its

*W J McGee, Eleventh Annual Report, U. S. Geol. Survey, for 1889-90, Part I, pp. 486-496. Summaries of observations of the interglacial forest beds throughout this region, with discussion of their significance, are given by C. Whittlesey, Smithsonian Contributions, No. 197, vol. xv, 1864, pp. 13-15; J. S. Newberry, Geology of Ohio, vol. ii, 1874, pp. 30-33; N. H. Winchell, Proc. A. A. A. S., vol. xxiv, for 1875, Part II, pp. 43-56; G. F. Wright, The Ice Ace in North America, 1889, pp. 475-496; Frank Leverett, Proc. Boston Soc. Nat. Hist., vol. xxiv, pp. 455-459, Jan. 1, 1890, and Journal of Geology, vol. i, pp. 129-146, with map, Feb.-March, 1893. N. H. Winchell, Geology of Minn., Final Report, vol. i, 1884, pp. 313, 363, 390.

†Geology of Minn., Final Report, vol. i, 1884, pp. 402, 406, 466, 479-485, 507, 511, 552, 580, 581, 585-6, 609, 625; vol. ii, 1888, pp. 138, 186, 187, 199, 466, 529, 555, 662, 668.

continuation past Brown's Valley and above the bed of lake Traverse, channeled then apparently about 50 feet (or more) below the general surface of the adjoining country to the level of the Herman beach of lake Agassiz,* finds full explanation in this retreat of the ice-sheet to the vicinity of Mitchell and Barnesville, 200 to 250 miles inward from its farthest limits in North Dakota and on the northern boundaries of the Wisconsin driftless area, but 500 miles north from its limits in Kansas and Missouri.

During the ensuing stage of its renewed accumulation and growth, the ice-sheet reached from Barnesville about 200 miles westward into North Dakota, an equal distance eastward into northwestern Wisconsin and southeastern Minnesota, and some 350 miles or more south-southeastward in Iowa. Not only were the interglacial forest beds thus covered, but a marginal moraine, which had been formed probably during a slight pause or re-advance interrupting the later part of the intermediate glacial retreat, was likewise buried and is now indicated by exceptionally abundant boulders in a stratum of the drift shown in the cliffs of the upper part of the Minnesota river valley and by its tributaries, overspread by 25 to 50 feet of the later deposits of till.†

The two stages of growth of the ice-sheet may have been due, aside from their principal dependence on the high elevation of the land, to the climatic effects of the last two passages in the precession of the equinoxes, with accompanying nutation, bringing the winters of the northern hemisphere in aphelion about 30,000 years ago and again about 10,000 years ago. The intermediate time of the earth's northern winters in perihelion would be the stage of great retreat of the ice margin in the upper Mississippi region; but eastward, from Ohio to the Atlantic coast, there appears to have been little glacial oscillation.‡ This explanation accords with Prof. N.H. Winchell's computations from the rate of recession of the falls of St. Anthony for the Postglacial or Recent period,§ and with his estimate of the duration of the interglacial stage from the now buried channel which appears to have been then eroded

*Proc. Am. Assoc. for Adv. of Science, vol. xxxii, for 1883, pp. 222-227. Geology of Minn., vol. i, pp. 479-485, 507, 580; vol. ii, pp. 134, 172, 216, 519-525.

†Geology of Minn., vol. i, p. 626.

‡J. D. Dana, Am. Jour. Sci., III, vol. xlvi, pp. 327-330, Nov., 1893.

§Geol. and Nat. Hist Survey of Minnesota, Fifth Ann. Rep., for 1876, pp. 175-189: Final Report, vol. ii, 1888, pp. 313-341, with fifteen plates (views showing recent changes of the falls of St. Anthony, and maps). Quart. Jour. Geol. Soc., London, vol. xxxiv, 1878, pp. 886-901.

by the Mississippi river a few miles west of the present gorge below these falls.*

The chief cause of the Ice age is here thought to have been a high epeirogenic uplift; but the very noteworthy subdivision of the Glacial epoch in the upper Mississippi basin is ascribed to climatic conditions resulting from the same astronomic cycle of 21,000 years which Croll supposed to have been efficient, during the remote time of maximum eccentricity of the earth's orbit, to produce alternating glacial and interglacial epochs. Wallace, in his discussion of this subject in "Island Life," thinks that great altitude of the glaciated countries coincided with the last stage of maximum eccentricity, from 240,000 to 80,000 years ago, to cause the Ice age, altitude and eccentricity being thought perhaps of nearly equal influence. The view here presented looks on the Glacial period as occurring in a much later time of low eccentricity, and for its causation regards altitude as far more efficient than any astronomic conditions. The effects of varying astronomic conditions have been recently reconsidered by Dr. George F. Becker,† who thinks, altogether differently from Croll, Geikie, and Ball, that the combination of minimum eccentricity of the earth's orbit and maximum obliquity of the ecliptic is most favorable for snow and ice accumulation; and he states that these conditions have existed within the past 40,000 years, until 8,000 years ago, but he apparently would attribute a larger share of the causes of glaciation to geographic conditions, as land elevation. In Europe a very remarkable parallelism of the history of the Ice age with that in America‡ indicates dependence on similar causes, chiefly geographic, as epeirogenic movements, with changes of ocean currents, and subordinately astronomic.

This view, and the following tabulation of the Pleistocene glacial and interglacial epochs and stages in America may show good ground for compromise and harmony between the lately opposing doctrines of unity and of duality or greater complexity of the Ice age. If this period extended through 30,000 or 50,000 years, depending principally on epeirogenic uplifts and in less degree on the cycles of precession of the equinoxes, it would agree well with Geikie's and Chamberlin's

*Am. Geologist, vol. x, pp. 69-80, with three plates (sections and a map), Aug., 1892.

†Am. Jour. Sci., III, vol. xlviii, pp. 95-113, Aug., 1894.

‡James Geikie, The Great Ice Age, three editions, 1873, 1877, and 1894, notably pp. 774, 775, in the third edition; Journal of Geology, vol. ii, p. 739. Oct.-Nov., 1894; Am. Geologist, vol. xv, p. 54, Jan., 1895.

complex history of wavering glaciation, and also with its essential geologic unity and brevity which have been insisted on by Dana, Wright, Hitchcock, Lamplugh, Kendall, Falsan, Holst, Nikitin, and other glacialists. To my mind the diversity and the unity of this period seem like the opposite gold and silver sides of the proverbial shield, concerning which two knights, each having seen only one side, valiantly contended.

Widely extended depression of the ice-burdened land, until mostly it had somewhat less altitude than now, initiated the comparatively short final epoch of the Glacial period. Temperate and warm climatic conditions on the ice border, nearly as now on the same latitudes, then melted away the ice rapidly; its chief stage of loess deposition attended the early part of this glacial retreat; the partially unburdened land began to rise by a moderate uplift, approximately proportional to the glacial melting and nearly keeping pace with it; and conspicuous belts of morainic drift were amassed whenever the steep waning ice-front slackened its departure, or halted, or for any short time re-advanced. The general but fluctuating retreat of the ice-sheet at length uncovered all the country and constituted the closing or Champlain epoch of the Ice age, so named from the marine beds of that time overlying the till in the basin of lake Champlain and along the St. Lawrence and Ottawa valleys, by which the vertical extent of the subsidence terminating the Glacial period and of the succeeding re-elevation is measured.

Adopting the helpful new nomenclature proposed by Chamberlin,* we may provisionally formulate the minor time divisions of the Glacial and Champlain epochs as follows. The order of this table, as of the former more comprehensive one, is stratigraphic, so that for the advancing sequence in time it should be read upward.

NOTE. If we seek to compare this table with the Glacial series in Europe, it should first be remarked that in the Alps there were three chief stages of growth of the glaciers far beyond their present limits, the second being the maximum advance, doubtless contemporaneous, as shown by Geikie, with the maximum extension of the ice-sheet upon northern Europe. The first glacial stage of the Alps, which also appears to have left traces in southern Sweden not wholly obliterated by the next and greater glaciation, may be represented in America by the till beneath

*In two chapters (pages 724-775, with maps forming plates xiv and xv) of J. Geikie's "The Great Ice Age," third edition, 1894, Prof. T. C. Chamberlin proposes a chronologic classification of the North American drift under three formations, named in the order of their age, beginning with the earliest, the Kansan, East Iowan, and East Wisconsin formations.

the interglacial lignite in the basin of James bay, and these may belong to the time of northern winters in aphelion some 50,000 years ago. The second, third, and fourth glacial stages of the European Ice age, as tabulated by Geikie, are then seen to be wholly analogous in characteristics of ice extension and drift deposition, and they were probably also time equivalents, respectively, with the Kansan, Iowan, and Wisconsin stages in the United States and Canada. In each continent the interglacial time between the Kansan and Iowan stages had great subaërial erosion because of the continuing high elevation of the land; and the latest or moraine-forming stage of the glaciation seems, alike in Europe and America, to have belonged to the mainly rapid but fluctuating final retreat of the ice, showing, as I think, that each ice-sheet had in its lower part much englacial drift.

Epochs and Stages of the Glacial Period.

CHAMPLAIN EPOCH. (Land depression; disappearance of the ice-sheet; partial re-elevation of the land.)	WISCONSIN STAGE.. (Progressing re-elevation.)	Moderate re-elevation of the land, advancing as a permanent wave from south to north and northeast; continued retreat of the ice along most of its extent, but its maximum advance in southern New England, with fluctuations and the formation of prominent marginal moraines; great glacial lakes on the northern borders of the United States; slight glacial oscillations, with temperate climate nearly as now, at Toronto and Scarboro'; the sea finally admitted to the St. Lawrence, Champlain, and Ottawa valleys; uplift to the present hight completed soon after the departure of the ice. (The great Baltic glacier, and European marginal moraines.)
	CHAMPLAIN SUBSIDENCE....	Depression of the ice-covered area from its high Glacial elevation; retreat of the ice from its former Iowan limits; abundant deposition of loess.
GLACIAL EPOCH... (Ice accumulation, due to the culmination of the Lafayette epeirogenic uplift.)	IOWAN STAGE......	Renewed ice accumulation, covering the forest beds and extending south nearly to its early boundary. (Third European glacial stage.)
	INTERGLACIAL STAGE...........	Extensive glacial recession in the upper part of the Mississippi basin; cool temperate climate and coniferous forests up to the waning ice border; much erosion of the early drift.
	KANSAN STAGE.....	Maximum extent of the ice-sheet in the interior of North America, and also eastward in northern New Jersey. (Maximum glaciation in Europe.)
	UNDETERMINED STAGES of fluctuation in the general growth of the ice-sheet.	Including an early glacial recession and readvance, as shown by beds of interglacial lignite in the region of the Moose and Albany rivers, tributary to James bay. (First glacial stage in the Alps.)

VII.

NOTES ON MINNESOTA MINERALS.

BY CHAS. P. BERKEY.

CONTENTS.

Several minerals already well known in Minnesota and others not recognized in former reports as occurring in this state have been analyzed and reported to the Minnesota Academy of Natural Sciences from time to time. The investigations have been carried on in the laboratories of the University of Minnesota, and the materials furnishing the basis of these notes are among the specimens of the department of geology and mineralogy.

MINERALS FROM AMYGDALOIDAL DIABASE AT GRAND MARAIS.

Nos. 1541 to 1548 inclusive are all from Grand Marais, and together form a group of specimens which was originally a geode in the amygdaloidal diabase at that place. The rock in which the minerals was found is an altered phase of the diabase so well known in the Lake Superior region. The rock attached to the minerals and in immediate contact is of a dark brown color sometimes tinged with green; and the vesicles, filled and partly filled, are so abundant as to make up almost half of the bulk of the rock. All of them, however, are comparatively small, the average being about one-fourth of an inch in length. Most of them are well filled with one or more of the minerals, calcite, laumontite, strigovite, apophyl-

lite and quartz. Among these, laumontite and strigovite fill the greater number of amygdules. Quartz is present in small quantities.

Thin sections of this rock show that the original augitic constituent has entirely disappeared and a greenish chloritic substance has in part taken its place. The feldspar constituent has altered so much that few places are sufficiently fresh to ground a determination upon. Tests indicate labradorite. Quartz is found sparingly, lining some of the cavities and filling some of the small fissures. It also sometimes forms a thin layer between the calcite and the rock.

Chlorite is found scattered throughout the section. It may be, however, that it is not identical with that filling the amygdules.

The calcite is at several places developed into imperfect crystals of dog tooth spar. The greater part, however, is found filling the cavities and spaces between the other minerals. It is almost pure $CaCO_3$, carrying only a trace of $MgCO_3$ and 0.15 per cent. of insoluble matter.

This rock gave the following chemical analysis:

ANALYSIS OF AMYGDALOIDAL DIABASE.

SiO_2	55.40	per cent.
Al_2O_3	22.55	" "
Fe_2O_3	14.67	" "
FeO	3.75	" "
MgO	.74	" "
CaO	1.41	" "
H_2O	.97	" "
Total	99.49	

Apophyllite.

This mineral partially filled the geode with numerous small well formed crystals. It is the first occurrence of the mineral noted in Minnesota. The crystals are partially imbedded in the laumontite and also in direct contact with both the calcite and the rock. All are colorless to white and are transparent to translucent. Few measurements have been made, but the forms are easily determined. The only forms noted are: ∞P, $P\infty$, $0P$, comprising the prism of the second order, pyramid of the first order, and basal pinacoid. Although there are so few forms, there is considerable variety in the degree to which one form in the combination predominates over the other. Some of the surfaces are so heavily striated as to

seriously interfere with measurements by reflection. Some of the smallest crystals are very pure and clear. The specific gravity of the best material is 2.34. All the reactions and characters agree with apophyllite.

In obtaining material for analysis a good deal of difficulty was experienced from the laumontite, which penetrates all the crystals to such an extent that only very minute fragments of sufficient purity could be obtained. The centre of nearly every crystal is occupied by needles of pink laumontite, and in thin sections they can be traced even further into the clearest portion. One of the elements usually found in apophyllite, fluorine, was not found in sufficient quantity to estimate, although a trace of it is indicated by qualitative tests.

ANALYSIS OF APOPHYLLITE

SiO_2	52.61	per	cent.
Al_2O_3	.67	"	"
Fe_2O_3	trace.		
CaO	25.22	"	"
MgO	.17	"	"
K_2O	3.03	"	"
Na_2O	1.71	"	"
HFl	trace.		
H_2O	16.17	"	"
Total	99.58		

In this analysis both Al_2O_3 (.67 per cent.) and the trace of Fe_2O_3 are probably due to the minute needles of laumontite that could not be avoided in the selection of material.

Laumontite.

This mineral fills many of the amygdules. It is in fine needles and in places is partially broken down to a powder. The needles pierce the calcite as well as the apophyllite. This is one of the most common of the minerals of the amygdaloidal rock at many other places.

ANALYSIS OF LAUMONTITE.

SiO_2	53.87	per	cent.
Al_2O_3	18.06	"	"
Fe_2O_3	.88	"	"
CaO	11.19	"	"
MgO	.45	"	"
K_2O	.29	"	"
Na_2O	.67	"	"
H_2O	13.18	"	"
Total	98.59		

Strigovite.

The chloritic mineral which is referred to strigovite fills many of the amygdules as closely fitting pellets of a soft green substance which does not cling to the walls and can be easily removed entire. The outer smooth surface of each pellet is usually covered with a light brown powdery coating. There is throughout a definite fibrous arrangement shown in thin section. Good sections across these amygdules are difficult to obtain, however, on account of the difference in hardness of the parts. But with the aid of such a section it is not entirely certain that the green alteration product, already referred to in speaking of the rock, scattered in small quantities through the section, is identical with the green mineral filling the amygdules. It resembles in all respects the "viridite", "delessite", "chloritic substance", etc. of writers on these rocks. It was with a good deal of satisfaction that finally a full chemical analysis was completed of this green mineral from the amygdules.

ANALYSIS OF STRIGOVITE.

SiO_2	33.14	per cent.
Al_2O_3	13.22	" "
Fe_2O_3	24.20	" "
FeO	12.19	" "
CaO	1.50	" "
MgO	3.49	" "
H_2O	12.34	" "
Total	100.08	

This chemical analysis agrees more closely with *strigovite* than with any other of the chlorites.

DATOLITE.

No. 1518 is datolite. Several specimens of this mineral have been found on the lake shore near Flood bay in sec. 29, T. 53 N., R. 10 W., by Mr. Brandt and Mr. A. H. Elftman.

The color of the mineral is almost pure white; shape, nodular; texture, compact and very finely crystalline. The specimens show a conchoidal fracture and have an opaque, somewhat earthly appearance. The microscope and thin section reveal a micro crystalline structure. The hardness is about 4.5 and the specific gravity 2.9. Small fragments are easily fusible with intumescence to a clear glass and give off water. All tests agree perfectly for *datolite*.

ANALYSIS OF DATOLITE.

SiO_2	36.90	per cent
Al_2O_3 and Fe_2O_3	1.51	" "
CaO	35.67	" "
B_2O_3 by diff.	20.32	" "
H_2O	5.60	" "
Total	100.00	

The Lake Superior region is the only locality reporting this variety of datolite. These specimens are similar in all physical characters to the mineral reported by Prof. J. D. Whitney* from the vein stuff of the Minnesota mine on the south shore of lake Superior. And the chemical analysis varies but little from that given by Chandler.†

Datolite is found chiefly as a secondary mineral in basic eruptives with such associated minerals as calcite prehnite and various zeolites. All these conditions are met at Flood bay, but so far no specimen of this mineral has been taken from the rock in place. From its occurrence among the pebbles where foreign debris is to some extent mingled with that of local derivation, it is evident that the mineral may have a drift origin. The direction of the later glacial movements would make it possible for these pebbles to be carried from the localities where this variety has long been known, and deposited as drift where they are now found. Therefore the only positive fact of its occurrence in Minnesota is, that datolite is found as nodules among the pebbles on the shore of lake Superior.

TRAVERTINE.

In connection with certain questions relating to the Magnesian series of rocks in Minnesota, the travertines from some of the limestone and dolomyte beds have been investigated. One specimen was selected from the compact travertine as it occurs at Minneapolis to represent a deposit from a limestone. The other is from a similar deposit, occurring near Osceola, Wis., representing the dolomytes. The Minneapolis material is not the product of a typical limestone, although the percentage of $MgCO_3$ is comparatively low. The Osceola material is deposited beside almost a typical dolomyte.

*Amer. Jour. Sci., II, vol. xxviii, pp. 12-13, 1859.
†Ibid., p. 13.

It is beyond my present purpose to discuss any bearing such analyses may have upon those questions which incited the investigation. It is sufficient to give the results of these analyses for the equal benefit of those following similar lines of research.

ANALYSES OF TRAVERTINE.

	Minneapolis.	Osceola.
$CaCO_3$	98.01	98.20
$MgCO_3$	1.44	1.75
Totals	99.45	99.95

MARL.

No. 1549.—Recently upon draining a slough at Fergus Falls, a bed of marl was found beneath about two feet of black mud. The marl bed is reported as having a thickness of from two to two and a half feet. It is a soft loose shell deposit in which many of the shells are still quite well preserved. In color it is light gray. It easily crumbles for the most part to a fine powder. An investigation of this material was desired in order to estimate its value as a fertilizer. And, because like deposits may be found in many other localities, it seems advisable to render some general opinion of their value.

ANALYSIS OF MARL.

Insoluble portion:—largely SiO_2	4.010	per cent.
Soluble portion:—$Al_2O_3+Fe_2O_3$	1.160	" "
CaO	50.402	" "
MgO	2.144	" "
CO_2	41.825	" "
P_2O_5	.126	" "
Loss and organic matter	.333	" "
Total	100.00	

Estimating the lime and magnesia as carbonates we should have the following percentages:

$CaCO_3$	89.744
$MgCO_3$	4.480
$Ca_3P_2O_8$	.275

It is safe to predict that other marl beds in our state will give essentially the same results. The variable constituents would most likely be an increased amount of the insoluble matter and a corresponding decrease of calcium carbonate. Under slightly different circumstances the organic matter is

much increased as a natural consequence of the gradual shallowing of the lake or pond and the establishing of conditions favorable to the formation of peat. It is not probable that phosphoric acid is present in any of our marls in sufficient quantity to be of much economic importance. Two other samples of marl taken from other localities give the same reactions, and the different constituents would show little variation from the amounts given above.

In some of the states marl is extensively used as a fertilizer. The most valuable, however, have been the greensands which are much used in New Jersey, and the results of an extended series of investigations are given in the annual report for 1886 by the state geologist. Those points in his conclusions upon the relative value of marls, which bear directly upon the present case, may be briefly stated as follows:

1. The most valuable marls are those which contain the largest percentage of phosphoric acid. The value of this constituent is about 6 cents per pound. The percentage multiplied by 20 will give the number of pounds per ton.

2. The most durable marls are those containing large quantities of carbonate of lime. When a marl crumbles to a fine powder it is more valuable than the coarser material.

3. All forage crops are particularly improved by marls. The green marls are spread upon the surface in the field to the amount of from 100 to 400 bushels per acre. Other marls must be used in larger quantities, but will produce good results.

4. The beneficial effect of one application of green marl has been observed to last for from 12 to 15 years.

One of the best sources of information is the work entitled: "Agriculture in some of its Relations with Chemistry," by F. H. Storer. The points of direct importance are condensed into the following:

1. Carbonate of lime tends to prevent puddling of clayey soils. The stone-like clods found in certain qualities of clay are serious hindrances to plant growth and are often improved by marls. After rains clays becomes less sticky.

2. The improvement of the texture of clayey soils is a practical fact of the very first importance.

3. Generally speaking, unless appreciable quantities of phosphoric acid are present, it is only the carbonate of lime in a marl that gives it fertilizing power. Marls can rarely do any harm for there is nothing hurtful in them.

4. The physical condition of the marl has much to do with its value. Easily pulverizable varities are best. They must fall to powder under the action of the atmosphere.

5. Carbonate of lime is helpful for nitrification.

6. "Root crops" are more subject to disease and failure on soils lacking lime. On poor sandy soils the best fertilizers are never so beneficial and lasting in their effect as when marl or lime has been first applied.

The points noted above are sufficiently clear. There is, however, among writers on this subject a wide diversity of views as to the importance and true value of marls. The present tendency is certainly more favorable to them. It is a well-recognized fact among geologists that limestone areas are pre-eminently fertile. It seems reasonable that increasing such constituents in other soils would be invariable beneficial.

In concluding this part of the subject, we must note that calcium carbonate, which forms almost ninety per cent. of the marl, is the material most in question. Therefore marl would prove most beneficial:

1. On poor sandy soils with other fertilizers.
2. On heavy clay soils, chiefly to improve the texture.
3. On soils soured and too acid, in affording the alkaline condition essential to nitrification and the preparation of plant foods.
4. On soils lacking a lime constituent.

The physical condition of the marl is very favorable for easy application and complete crumbling. The ease with which similar marls may be obtained in many places, while other fertilizers are comparatively expensive, will no doubt make this subject more important as an economic question as the need of a fertilizer becomes more apparent.

A point not yet touched upon, and needing only to be mentioned is—that marls of so high a percentage of calcium carbonate will burn to a good lime for local use. In case the soil is not of such nature as to require the marl, this other use may prove of value. In some cases a very good quality of lime can certainly be produced.

Some of the shells in this marl were very well preserved, although all of them are frail. In order to make comparisons with the fauna of our present lakes it became necessary to

have the species determined. Accordingly, a sample of the marl including some of the best shells was sent to Mr. H. A. Pilsbry, of Philadelphia, who has reported the following:

1. *Planorbis bicarinatus* Say.
2. " *campanulatus* Say.
3. " *parvus* Say.
4. " *deflectus* Say.
5. " *exacutus* Say.
6. *Limnæa galbana* Say.
7. *Physa elliptica* Lea.
8. *Valvata tricarinata* Say.
9. *Amnicola limosa* Say.
10. " *lustrica* Pilsbry.
11. *Pisidium abditum* Haldeman.
12. *Sphærium.* Fragments only. Species undetermined.

Mr. Pilsbry further remarks that No. 6, *Limnæa galbana* Say, was described from the bed of a small lake in New Jersey and is not known to occur living. It is, however, closely allied to a recent species. There is nothing in the shells to indicate any especially different climate from that of Minnesota or Michigan to-day, although a similar modern pond would be likely to produce certain large species of *Limnæa* in Minnesota, such as *L. stagnalis*, *reflexa*, *palustris*, etc.

All of these species except Nos. 6 and 10, *Limnæa galbana* Say, and *Amnicola lustrica* Pilsbry, have been reported from the lakes and rivers of our state. *L. stagnalis* and *L. palustris* are noted by both Dr. U. S. Grant and Prof. J. M. Holzinger in the 16th Ann. R. of the Minn. Geological and Nat. Hist. Survey. Several species of *Sphærium* have also been reported.

A further examination of this marl, when larger quantities can be obtained, will no doubt add to this list. Until this part of the subject can be more thoroughly investigated no conclusions or remarks can have any definite value.

I am indebted to C. A. Ballard, Supt. of the Fergus Falls schools, for the material with which all the work has been done; and to H. A. Pilsbry, conservator of the conchological section of the Acad. of Nat. Sci., Philadelphia, for his aid in this note.

VIII.

CHEMICAL ANALYSES.

Below are given the results of the chemical work done for the survey since the analyses last reported (19th Ann. Rept., pp. 121-127). These analyses were made by Prof. J. A. Dodge, Prof. C. F. Sidener, Mr. A. D. Meeds and Mr. A. J. Hammond, in the chemical laboratory of the University of Minnesota, and the following report of them was prepared under the direction of Prof. G. B. Frankforter.

CHEMICAL SERIES NO. 217.

Pyroxene. Analysis by C. F. Sidener.

Silica	SiO_2	53.19	per cent.
Alumina	Al_2O_3	2.38	" "
Ferric oxide	Fe_2O_3	9 25	" "
Ferrous oxide	FeO	5.15	" "
Lime	CaO	17.81	" "
Magnesia	MgO	9.43	" "
Potassa	K_2O	.38	" "
Soda	Na_2O	2.63	" "
Water	H_2O	.01	" "
Total		100 23	

CHEMICAL SERIES NO. 218.

"Soft" copper. Analysis by J A. Dodge.

Lead	Pb	slight trace.	
Antimony	Sb	trace.	
Iron	Fe	.06	per cent.
Sulphur	S	.03	" "
Copper (by diff.)	Cu	99.91	" "
Total		100.00	

The "soft" copper is well refined.

CHEMICAL SERIES NO. 219.

"Hardened" copper. Analysis by J. A. Dodge.

Lead	Pb	trace.	
Antimony	Sb	.36	per cent.
Iron	Fe	1.34	" "
Sulphur	S	.33	" "
Phosphorus	P	.01	" "
Copper (by diff.)	Cu	97.96	" "
Total		100.00	

The analysis seems to show that the "hardened" sample is nothing but unrefined or imperfectly refined copper, containing foreign substances derived from the ore.

CHEMICAL SERIES NO. 220.

Iron ore. Analysis by C. F. Sidener.

Silica	SiO_2	10.25	per cent.
Alumina	Al_2O_3	.98	" "
Ferric oxide (Fe=59.241)	Fe_2O_3	84.63	" "
Water	H_2O	4.01	" "
Phosphorus	P	.046	" "
Manganese	Mn	trace.	
Magnesium	Mg	trace.	
Calcium	Ca	none.	
Sulphur	S	none.	
Total		99.916	

CHEMICAL SERIES NO. 221.

Sample of rock. Analysis by C. F. Sidener.

Silica	SiO_2	52.94	per cent.
Alumina	Al_2O_3	14.70	" "
Ferric oxide	Fe_2O_3	2.52	" "
Ferrous oxide	FeO	7.80	" "
Lime	CaO	6.56	" "
Magnesia	MgO	4.49	" "
Potassa	K_2O	.04	" "
Soda	Na_2O	3.09	" "
Carbonic acid	CO_2	4.86	" "
Water	H_2O	2.04	" "
Total		99.04	

CHEMICAL SERIES NO. 222.

Sample of rock. Analysis by C. F. Sidener.

Silica	SiO_2	60.61	per cent.
Alumina	Al_2O_3	16.61	" "
Ferric oxide	Fe_2O_3	1.97	" "
Ferrous oxide	FeO	5.09	" "
Lime	CaO	4.46	" "
Magnesia	MgO	3.10	" "
Potassa	K_2O	.25	" "
Soda	Na_2O	3.11	" "
Carbonic acid	CO_2	1.57	" "
Water	H_2O	2.45	" "
Total		99.22	

Chemical Series No. 223.

Supposed bog manganese. Analysis by J. A. Dodge.

Found only a trace of manganese, the material being clay mixed with peaty matter.

Chemical Series No. 224.

Feldspar. Analysis by J. A. Dodge.

Silica	SiO_2	51.45 per cent.
Alumina	Al_2O_3	31.94 " "
Ferric oxide	Fe_2O_3	trace.
Lime	CaO	14.31 per cent.
Magnesia	MgO	.27 " "
Soda	Na_2O	.85 " "
Potassa	K_2O	.21 " "
Water	H_2O	.68 " "
Total		99.71

Chemical Series No. 225.

Supposed bog manganese. Analysis by J. A. Dodge.

Carbonaceous matter (by equation)		57.16 per cent.
Silica	SiO_2	28.55 " "
Alumina	Al_2O_3	5.19 " "
Ferric oxide	Fe_2O_3	.98 " "
Black oxide of manganese	MnO_2	.48 " "
Total		92.36

CaO, MgO, Na_2O, K_2O, CO_2, SO_3 and P_2O_5 present but not determined quantitatively.

Analysis of Mineral Water.

Sample of water from a deep well at St. James, Minn., at depth of about 500 feet. Analysis by J. A. Dodge.

Mineral matter in suspension	844.47 grains per U. S. gal.
" " " solution	130.88 " " " "
Total	975.35 grains per U. S. gal.

Composition of matter in suspension:

Oxide of iron	large quantity.
Carbonate of lime	small "
Clay	very large quantity.

Composition of matter in solution:

Sulphate of lime	103.19 grains per U. S. gal.
Carbonate of lime	moderate quantity.
" " magnesia	small "
Chloride of sodium	" "
Potash salts	" "

Reaction slightly alkaline.

The water was very turbid with red clay; it was easily clarified by filtration through paper.

CHEMICAL SERIES NO. 226.

Granite. Analysis by J. A. Dodge.

Silica	SiO_2	66.84	per cent.
Phosphoric oxide	P_2O_5	trace.	
Alumina	Al_2O_3	18.22	" "
Ferric oxide	Fe_2O_3	2.27	" "
Ferrous oxide	FeO	.20	" "
Lime	CaO	3.31	" "
Magnesia	MgO	.81	" "
Potassa	K_2O	2.80	" "
Soda	Na_2O	5.14	" "
Water	H_2O	.46	" "
Total		100.05	

CHEMICAL SERIES NO. 227.

Feldspar. Analysis by C. F. Sidener.

Silica	SiO_2	67.99	per cent.
Alumina	Al_2O_3	19.27	" "
Ferric oxide	Fe_2O_3	.82	" "
Lime	CaO	.75	" "
Magnesia	MgO	.02	" "
Potassa	K_2O	3.05	" "
Soda	Na_2O	6.23	" "
Water	H_2O	.90	" "
Total		99.03	

CHEMICAL SERIES NO. 228.

Hornblende porphyryte. Analysis by J. A. Dodge.

Silica	SiO_2	60.32	per cent.
Phosphoric oxide	P_2O_5	.12	" "
Alumina	Al_2O_3	15.80	" "
Ferric oxide	Fe_2O_3	5.42	" "
Ferrous oxide	FeO	.89	" "
Lime	CaO	4.65	" "
Magnesia	MgO	5.08	" "
Potassa	K_2O	1.82	" "
Soda	Na_2O	4.09	" "
Water	H_2O	1.67	" "
Total		99.86	

CHEMICAL SERIES NO. 229.

Winnebago meteorite. Analysis by C. F. Sidener.

Silica	SiO_2	38.23	per cent.
Alumina	Al_2O_3	2.39	" "
Ferrous oxide	FeO	5 94	" "
Chromic oxide	Cr_2O_3	.42	" "
Lime	CaO	1.64	" "
Magnesia	MgO	23.20	" "
Potassa	K_2O	.14	" "
Soda	Na_2O	.81	" "
Iron	Fe	23.27	" "
Nickel	Ni	1.67	" "
Cobalt	Co	.07	" "
Manganese	Mn	trace	
Copper	Cu	trace	
Sulphur	S	2.08	" "
Phosphorus	P	0.14	" "
Graphite	C	trace	
Total		100.00	

CHEMICAL SERIES NO. 230.

Metallic part of Winnebago meteorite. Analysis by C. F. Sidener.

Iron	Fe	87.05	per cent.
Nickel	Ni	12.28	" "
Cobalt	Co	.217	" "
Copper	Cu	trace	
Phosphorus	P	.028	per cent.
Total		99.575	

CHEMICAL SERIES NO. 231.

Pellets from the Winnebago meteorite. Analysis by C. F. Sidener.

Silica	SiO_2	47.71	per cent.
Alumina	Al_2O_3	5.00	" "
Ferric oxide	Fe_2O_3	2.70	" "
Ferrous oxide	FeO	12.07	" "
Lime	CaO	4.86	" "
Magnesia	MgO	27.29	" "
Total		99.63	

CHEMICAL SERIES No. 232.

Quartz porphyry. Analysis by A. D. Meeds.

Silica	SiO_2	69.70 per cent.
Alumina	Al_2O_3	18.72 " "
Ferric oxide	Fe_2O_3	.65 " "
Ferrous oxide	FeO	.79 " "
Lime	CaO	2.25 " "
Magnesia	MgO	.45 " "
Soda	Na_2O	5.01 " "
Potassa	K_2O	1.68 " "
Water	H_2O	.71 " "
Total		99.96

CHEMICAL SERIES No. 233.

Granite. Analysis by A. D. Meeds.

Silica	SiO_2	69.34 per cent.
Alumina	Al_2O_3	17.25 " "
Ferric oxide (including FeO)	Fe_2O_3	2.46 " "
Lime	CaO	3.43 " "
Magnesia	MgO	1.18 " "
Soda	Na_2O	4.33 " "
Potassa	K_2O	·71 " "
Water	H_2O	1.17 " "
Total		99.87

CHEMICAL SERIES No. 234.

"Muscovado." Analysis by A. D. Meeds.

Silica	SiO_2	49.07 per cent.
Alumina	Al_2O_3	17.21 " "
Ferric oxide	Fe_2O_3	.46 " "
Ferrous oxide	FeO	12.68 " "
Lime	CaO	9.66 " "
Magnesia	MgO	3.60 " "
Soda	Na_2O	2.96 " "
Potassa	K_2O	trace.
Carbonic acid	CO_2	2.70 per cent.
Manganese	MnO	trace.
Water	H_2O	1.55 per cent.
Total		99.89

CHEMICAL SERIES NO. 235.

Taconyte. Analysis by C. F. Sidener.

Silica	SiO_2	86.35	per cent.
Alumina	Al_2O_3	.78	" "
Ferric oxide	Fe_2O_3	7.41	" "
Ferrous oxide	FeO	3.46	" "
Lime	CaO	.01	" "
Magnesia	MgO	.05	" "
Potassa	K_2O	.01	" "
Soda	Na_2O	.12	" "
Carbonic acid	CO_2	1.22	" "
Water	H_2O	.01	" "
Total		99.42	

CHEMICAL SERIES NO. 236.

Taconyte. Analysis by C. F. Sidener.

Silica	SiO_2	41.73	per cent.
Alumina	Al_2O_3	4.07	" "
Ferric oxide	Fe_2O_3	14.43	" "
Ferrous oxide	FeO	19.85	" "
Lime	CaO	.02	" "
Magnesia	MgO	4.41	" "
Potassa	K_2O	.02	" "
Soda	Na_2O	.18	" "
Carbonic acid	CO_2	5.76	" "
Water	H_2O	5.65	" "
Organic matter		3.50	" "
Total		99.62	

Also a trace of graphite.

CHEMICAL SERIES NO. 237.

Taconyte. Analysis by C. F. Sidener.

Silica	SiO_2	85.97	per cent.
Alumina	Al_2O_3	.67	" "
Ferric oxide	Fe_2O_3	11.40[1]	" "
Ferrous oxide	FeO	.90	" "
Lime	CaO	.01	" "
Magnesia	MgO	.02	" "
Potassa	K_2O	.01	" "
Soda	Na_2O	.01	" "
Water	H_2O	.30	" "
Total		99.29	

Chemical Series No. 238.

Silica-kaolin. Analysis by C. F. Sidener.

Silica	SiO_2	77.89	per cent.
Alumina	Al_2O_3	13.55	" "
Ferric oxide	Fe_2O_3	1.83	" "
Lime	CaO	trace	
Magnesia	MgO	.36	" "
Potassa	K_2O	.84	" "
Soda	Na_2O	.58	" "
Water	H_2O	4.45	" "
Total		99.50	

Chemical Series No. 239.

Taconyte. Analysis by C. F. Sidener.

Silica	SiO_2	61.57	per cent.
Alumina	Al_2O_3	16.83	" "
Ferric oxide	Fe_2O_3	5.27	" "
Ferrous oxide	FeO	6.41	" "
Lime	CaO	.01	" "
Magnesia	MgO	3.44	" "
Potassa	K_2O	1.59	" "
Soda	Na_2O	.12	" "
Water	H_2O	4.70	" "
Total		99.94	

Chemical Series No. 240.

Taconyte. Analysis by A. D. Meeds.

Silica	SiO_2	23.80	per cent.
Alumina	Al_2O_3	7.95	" "
Ferric oxide	Fe_2O_3	5.97	" "
Ferrous oxide	FeO	32.21	" "
Lime	CaO	4.67	" "
Magnesia	MgO	5.89	" "
Soda	Na_2O	.29	" "
Potassa	K_2O	.18	" "
Manganese	MnO	trace.	
Carbonic acid	CO_2	11.84	per cent.
Water	H_2O	4.28	" "
Organic matter		3.35	" "
Total		100.43	

Chemical Series No. 241.

Taconyte. Analysis by A. D. Meeds.

Silica	SiO_2	56.28	per cent.
Alumina	Al_2O_3	3.29	" "
Ferric oxide	Fe_2O_3	15.25	" "
Ferrous oxide	FeO	18.28	" "
Lime	CaO	.93	" "
Magnesia	MgO	.72	" "
Soda	Na_2O	.25	" "
Loss on ignition		4.75	
Total		99.75	

Chemical Series No. 242.

Silica powder. Analysis by A. D. Meeds.

Silica	SiO_2	98.17	per cent.
Alumina	Al_2O_3	.50	" "
Ferric oxide	Fe_2O_3	1.03	" "
Lime	CaO	trace	
Magnesia	MgO	trace	
Soda	Na_2O	.25	
Potassa	K_2O	trace	
Loss on ignition		.19	" "
Total		100.14	

Chemical Series No. 243.

Taconyte. Analysis by A. J. Hammond.

Silica	SiO_2	57.00	per cent.
Alumina	Al_2O_3	1.43	" "
Ferric oxide	Fe_2O_3	27.05	" "
Ferrous oxide	FeO	11.08	" "
Lime	CaO	.40	" "
Magnesia	MgO	2.02	" "
Potassa	K_2O	.113	" "
Soda	Na_2O	.397	" "
Loss on ignition		.91	
Total		100 400	

CHEMICAL SERIES NO. 244.

Taconyte. Analyses by A. D. Meeds.

Silica	SiO_2	64.04	per cent.
Alumina	Al_2O_3	2.11	" "
Ferric oxide	Fe_2O_3	2.81	" "
Ferrous oxide	FeO	22.14	" "
Lime	CaO	.60	" "
Magnesia	MgO	4.04	" "
Soda	Na_2O	.30	" "
Potassa	K_2O	.11	" "
Water	H_2O	3.73	" "
Loss on ignition		.67	" "
Total		100.55	

Another analysis of the same rock, which varies a great deal, gave:

Silica	SiO_2	58.94	per cent.
Alumina	Al_2O_3	2.72	" "
Ferric oxide	Fe_2O_3	3.01	" "
Ferrous oxide	FeO	22.94	" "
Lime	CaO	.71	" "
Magnesia	MgO	4.74	" "
Potassa	K_2O	.09	" "
Soda	Na_2O	.24	" "
Water	H_2O	3.35	" "
Carbonic acid	CO_2	3.72	" "
Total		100.46	

CHEMICAL SERIES NO. 245.

"Muscovado." Tested by A. D. Meeds.

Gave a strong qualitative test for titanium.

CHEMICAL SERIES NO. 246.

Glauconite. Analysis by A. D. Meeds.

Ferric oxide	Fe_2O_3	9.43	per cent.
Ferrous oxide	FeO	3.54	" "

CHEMICAL SERIES NO. 247.

Rock containing glauconite, siderite and silica. Analysis by A. D. Meeds.

Insoluble in HCl, as follows:

Silica	SiO_2	74.53	per cent.
Ferric oxide	Fe_2O_3	.34	" "
Alumina	Al_2O_3	.22	" "
		75.09	" "

Soluble in HCl, as follows:

Alumina	Al_2O_3	1.35 per cent.
Ferric oxide	Fe_2O_3	1.96 " "
Ferrous oxide	FeO	14.84 " "
Lime	CaO	.63 " "
Magnesia	MgO	.92 " "
Soda	Na_2O	.11 " "
Potassa	K_2O	.10 " "
Carbonic acid	CO_2	5.10 " "
Water	H_2O	.62 " "
		25.63

Of the FeO 8.35 per cent. is combined as $FeCO_3$, making 13.45 per cent. $FeCO_3$. The remaining 6.49 per cent. of FeO is combined as glauconite.

CHEMICAL SERIES NO. 248.

Glauconite. Analysis by A. D. Meeds.

Silica	SiO_2	47.12 per cent.
Alumina	Al_2O_3	2.60 " "
Ferric oxide	Fe_2O_3	3.51 " "
Ferrous oxide	FeO	28.48 " "
Lime	CaO	.61 " "
Magnesia	MgO	1.94 " "
Potassa	K_2O	.11 " "
Soda	Na_2O	trace.
Water	H_2O	2.70 per cent.
Carbonic acid	CO_2	13.49 " "
Total		100.46

DERIVATION OF THE FOREGOING SUBSTANCES.

Chem. Series 217.—Pyroxene from porphyritic augite soda granite; rock 86 Grant; N. W. corner of sec. 32, T. 65-6 W.; north shore of Kekequabic lake, Lake county. See Amer. Geol., vol. 11, p. 387, June, 1893; and 21st Ann. Rept., p. 48.

Chem. Series 218.—Metallic copper, nearly or quite pure, from Mr. Peter Johnson, Dassel, Minn.

Chem. Series 219.—"Hardened" metallic copper, nearly or quite pure, from Mr. Peter Johnson, Dassel, Minn.

Chem. Series 220.—Iron ore from pit No. 1, Cincinnati mine, Mesabi range. Representative sample of the Mesabi ore. See 20th Ann. Rept. p. 149.

Chem. Series 221.—Greenish felsyte (?), country rock at Ely; rock 1002.

Chem. Series 222.—Rock similar to the last, but from the interior of one of the rounded masses in the agglomerate at the railway cut at Ely; rock 1626. See Amer. Geol., vol. 9, pp. 359-368, June, 1892.

Chem. Series 223.—Supposed bog manganese (but really clay and peat), three miles N. W. of Monticello. See 19th Ann. Rept., pp. 80-81; and 20th Ann. Rept., pp. 321-322.

Chem. Series 224.—Anorthite, from cave at east of Split-rock point, north shore of lake Superior; rock 5 B Lawson. See Bull. No. VIII, p. 6.

Chem. Series 225.—Supposed bog manganese (really a peaty substance), Monticello. From Mr. J. N. Stacy. See 19th Ann. Rept., pp. 80-81; and 20th Ann. Rept., pp. 321-322.

Chem. Series 226.—Augite soda granite; rock 551 Grant; S. W. ¼ S. W. ¼ sec. 3, T. 64-7 W.; south shore of Kekequabic lake, Lake county. See Amer. Geol., vol. 11, p. 385, June, 1893; and 21st Ann. Rept., pp. 41-42.

Chem. Series 227. Anorthoclase from augite soda granite; rock 551 Grant; S. W. ¼ S. W. ¼ sec. 3, T. 64-7 W.; south shore of Kekequabic lake, Lake county. See Amer. Geol., vol. 11, p. 386, June, 1893; and 21st Ann. Rept., p. 44.

Chem. Series 228.—Hornblende porphyryte; rock 797 Grant; N. E. ¼ S. E. ¼ N. W. ¼ sec. 29, T. 65-6 W.; south end of Epsilon lake, Lake county. See 21st Ann. Rept., p. 58.

Chem. Series 229.—Winnebago meteorite, taken as a whole. Museum No. 7239.

Chem. Series 230.—The iron of the Winnebago meteorite. Museum No. 7239.

Chem. Series 231.—The rounded pellets of the Winnebago meteorite. Museum No. 7239.

Chem. Series 232.—Quartz porphyry, from a dike in the "greenstone" of the Kawishiwi river; rock 417 Grant; N. ¼ N. E. ¼ sec. 21, T. 63-10 W., Lake county. See 21st Ann. Rept., p. 43.

Chem Series 233.—Characteristic specimen of the Saganaga granite, a coarse grained hornblende granite; rock 686 Grant; S. W. ¼ N. E. ¼ sec. 22. T. 66-5 W.; Saganaga lake, Cook county. See 21st Ann. Rept., p. 43.

Chem. Series 234.—Fine grained gabbro ("granulitic gabbro") or "muscovado;" rock 857 Grant; near N. line of sec. 2, T. 64-5 W., Bashitanakueb lake, Cook county. See 21st Ann. Rept., pp. 150-151.

Chem. Series 235.—Sideritic chert banded with siliceous and chloritic slates; rock 27 Spurr; N. E. ¼ S. E. ¼ sec, 33, T. 58-17 W., St. Louis county. See Bull. No. X, p. 54.

Chem. Series 236.—Dark green spotted-granular taconyte (green-sandstone?); rock 53 Spurr; S. E. ¼ sec. 4, T. 58-16 W., St. Louis county. See Bull. No. X, p. 70.

Chem. Series 237.—Red siliceous jointed taconyte, somewhat decomposed; rock 65 Spurr; S. W. ¼ S. W. ¼ sec. 2, T. 58-18 W., St. Louis county. See Bull. No. X, p. 116.

Chem. Series 238.—Banded silica-kaolin; rock 70 Spurr; S. E. ¼ N. E. ¼ sec. 6, T. 58-17 W., St. Louis county. See Bull. No. X, p. 81.

Chem. Series 239.—Taconyte (?) shale; rock 101 Spurr; S. E. ¼ N. W. ¼ sec. 18, T. 58-18 W., St. Louis county. See Bull. No. X, p. 148.

Chem. Series 240.—Sideritic and cherty slate; rock 112 Spurr; N. W. ¼ N. E. ¼ sec. 17, T. 58-19 W., St. Louis county. See Bull. No. X, pp. 10-11.

Chem. Series 241.—Glauconite taconyte, with magnetite; rock 217 Spurr; N. W. ¼ N. W. ¼ sec. 22, T. 58-20 W., St. Louis county. See Bull. No. X, p. 87.

Chem. Series 242.—Silica powder; rock 230 Spurr; S. E. ¼ N. W. ¼ sec. 23, T. 57-22 W., Itasca county. See Bull. No. X, p. 214.

Chem. Series 243.—Gray siliceous taconyte; rock 107 Spurr; S. W. ¼ S. W. ¼ sec 2, T. 58-19 W., St. Louis county. See Bull. No. X, p. 134.

Chem. Series 244.—Hard green taconyte, banded with magnetite; rock 14 Spurr; S. E. ¼ N. E. ¼ sec. 30, T. 58-17 W., St. Louis county. See Bull. No. X, pp. 103-104.

Chem. Series 245.—Fine grained noryte, or "muscovado"; rock 1784; north side of Muscovado lake, Cook county. See 21st Ann. Rept, p. 150.

Chem. Series 246.—Glauconite from St. Lawrence limestone; Museum No. 3292; Hebron, Nicollet county.

Chem. Series 247.—Glauconite and siderite from glauconitic taconyte; rock 125 Spurr; near N. E. ¼ S. W. ¼ sec. 17, T. 58-19 W., St. Louis county. See Bull. No. X, pp. 232-233.

Chem. Series 248.—Same as Chem. Series 247.

IX.

THE PROGRESS OF MINING.

BY N. H. WINCHELL.

The last statement in these reports concerning the product of the iron mines of the state was in the report for 1881, (20th report, pp. 152, 153.) Since that time the Legislature's "Blue Book" has contained such information, for 1892 and 1893. The years 1893 and 1894 exhibited, in the iron ore output from the state of Minnesota, a wonderful rate of increase as compared with the iron-producing states of the Lake Superior region. Financial revulsion visited the country in 1893, and continued through 1894, and the iron industry suffered great reverses. The output declined in the Marquette range in Michigan from 5,179,098 tons in 1891 and 1892, to 3,885,000 in 1893 and 1894. The decline on the Menominee range was from 4,086,118 tons, for the same time, to 2,604,146 tons. The Gogebic range fell off, for the same time, from 4,797,590 tons to 3,163,550 tons. In the Vermilion range the decline was slight, being from 2,064,165 tons to 1,774,320 tons. But the rapid development of the Mesabi range showed an increase from 4,245 tons in 1892 (first year of shipment) to 2,402,067 tons for 1893 and 1894. This so far overbalanced the loss on the Vermilion range that the state showed an increase from 2,064,933 tons in 1891 and 1892 to 4,176,387 tons for 1893 and 1894, which is about 100 per cent.

Accompanying the development of the iron industry have come many other industries, and other elements of financial and political growth. These, however, are not so important nor so numerous as they are destined to be in the near future. The whole region about the west end of lake Superior has felt the impulse of this development, and new improvements are projected on all hands, which when carried out will bring the

northeastern part of the state into prominence as a manufacturing and commercial power.

The following figures show the actual production of iron ore from the mines of Minnesota by years, since 1884:

	Vermilion range.		Mesabi range.	
Product in 1884	62,124	tons.		
" 1885	225,484	"		
" 1886	307,948	"		
" 1887	394,910	"		
" 1888	511,935	"		
" 1889	844,638	"		
" 1890	880,290	"		
" 1891	896,515	"		
" 1892	1,167,650	"	4,245	tons.
" 1993	820,621	"	613,620	"
" 1894	953,699	"	1,788,447	"
Totals	7,065,832	tons.	2,406,312	tons.
Grand total for the state			9,472,144	tons.

Production of Iron Ore by Minnesota Mines to Dec. 31, 1894.

NOTE.—The following table agrees with other published statements of the Minnesota Survey in its reports and in the various Legislative Manuals, but it differs in some particulars from the figures given in the Marine Review, Cleveland, Ohio, Jan. 17, 1895. When such is the case the figures from this latter source are inserted in parentheses.

Name of Mine.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.	Totals.
Vermilion Range.												
Chandler	......	......	......	......	56,712 (54,612)	306,000 (306,220)	336,002	375,866 (373,969)	651,655	435,930	562,087 (558,050)	2,724,252 (2,716,438)
Minnesota	62,124	225,484	307,948 (304,396)	394,910 (394,252)	455,241 (457,341)	535,538 (535,318)	532,272 (532,000)	517,570	498,353	370,303	391,612 (390,463)	4,291,355 (4,287,604)
Pioneer	......	......	......	......	......	3,100 (3,144)	12,016 (12,012)	3,079	2,651	......	......	20,846 (20,886)
Zenith	......	......	......	......	......	......	......	......	14,991	14,388	......	29,379
Totals	62,124	225,484	307,948 (304,396)	394,910 (394,252)	511,953	844,638 (844,682)	880,290 (880,014)	896,515 (894,618)	1,167,650	820,621	953,699 (948,513)	7,065,832 (7,054,307)
Mesabi Range.												
Auburn	......	......	......	......	......	......	......	......	......	......	110,809 (108,210)	110,809 (108,210)
Biwabik	......	......	......	......	......	......	......	......	......	151,500	90,048	241,548
Canton	......	......	......	......	......	......	......	......	......	24,416	213,853	238,269
Cincinnati	......	......	......	......	......	......	......	......	......	26,372	......	26,372
Commodore	......	......	......	......	......	......	......	......	......	65,137	......	65,137
Duluth Iron Mining Co.	......	......	......	......	......	......	......	......	......	37,626	......	37,626
Franklin	......	......	......	......	......	......	......	......	......	46,617	223,399	270,016
Hale	......	......	......	......	......	......	......	......	......	3,616	24,167	27,783
Lowmore	......	......	......	......	......	......	......	......	......	1,645	......	1,645
Minnewas	......	......	......	......	......	......	......	......	......	13,858	2,140	15,998
Missabe Mountain	......	......	......	......	......	......	......	......	......	123,015	505,955	628,970
Mountain Iron	......	......	......	......	......	......	......	......	4,245	119,818	573,440	697,503
Norman	......	......	......	......	......	......	......	......	......	......	39,008 (38,999)	39,008 (38,999)
Vega	......	......	......	......	......	......	......	......	......	......	5,628	5,628
Totals	......	......	......	......	......	......	......	......	4,245	613,620	1,788,447 (1,785,839)	2,406,312 (2,403,704)
Grand Totals	62,124	225,484	307,948 (304,396)	394,910 (394,252)	511,953	844,638 (844,682)	880,290 (880,014)	896,515 (894,618)	1,171,895	1,434,241	2,742,146 (2,734,452)	9,472,144 (9,458,011)

X.

COMPRESSIVE STRENGTH OF SOME MINNESOTA BRICKS AND BUILDING STONES.

The following table shows the results of tests made at the request of the Minnesota State Commissioners of the Columbian Exposition, transmitted by Supt. L. P. Hunt. The data were kindly furnished by Col. C. McC. Reeve, Secretary. The tests were made at the Watertown Arsenal, Mass., May 21, 1894, under the direction of Maj. J. W. Reiley, Ordnance Department, U. S. A.

Test Number.	Description.	Marks.	Dimensions.			Sectional area. Sq. inches.	Weight, dry.		Absorption of Water.				First crack. Lbs.	Ultimate Strength.		Remarks
			Hight. Inches.	Compressed surface... Inches.	Compressed surface... Inches.		Lbs.	Oz.	Total. Lbs.	Total. Oz.	By Weight. Per cent.	By Volume. Per cent.		Total. Lbs.	Per sq. in. Lbs.	
6595	John Lind & Co., Barnum, Red Brick.		2.28	7.98	3.67	29 25	4	4¾	...	9½	13.8	24.7	36.000	80,200	2,742	
6596	Red Brick.	"From F. X. Goulet's yd., Staples, Min."	2.24	7.86	3 87	30.41	4	9¼	......	10	13.6	25.3	102,000	176,100	5.791	
6597	" "		2.15	7.54	3.72	28.05	4	2¾	....	7	10.5	20.	54,000	192,000	6,845	
6598	Buff Brick (light).		2 53	8.26	3.76	31.06	3	15¼	1	8	30.	41.8	46,800	46,800	1,507	From PeterBecker
6599	Buff Brick (light).	"Lundgren Bros., Warren Brick, New Quaker."	2.35	7.66	3.60	27.58	3	14¼	......	10½	16.8	27.9	56,000	147,200	5,337	
6600	Pearl color Brick.	"F A.NewUlm"	2.35	8.62	4.26	36.72	6	¼	......	10½	10.9	21.0	92,000	154,100	4,196	Has an elliptical panel on one face .27'' deep.
6601	Buff col'r Brick	"O. R. Mather Pelican Rapids, Minn."	2.27	8.17	3.92	32 03	3	13¼	1	½	26.7	39.2	106,000	111,800	3,475	
6602	Red Brick.		2.42	8.30	4.05	33.61	5	1¼	.....	18¾	16.9	29.2	66,000	92,000	2,737	

6603	Buff col'r Brick		2.40	8.08	3.88	31.35	4	6¼	...	13¾	19.6	31.5	109,000	214,200	6,833	From Fred Nathegreen, Carlton.
6604	" " "		2.43	7.93	3.52	27.91	3	15	......	11½	17.9	28.6	38,000	117,400	4,206	From Dangs & Wiest, Blakeley.
6605	" " "		2.38	7.84	3.50	27.44	3	14¼	......	11	17.7	29.1	44,000	114,500	4,173	" "
6606	" " "	"Ness & Moog, St. Cloud."	2.25	8.23	3.86	31.77	3	9¾	1	¼	28.1	39.3	98,000	140,300	4,416	
6607	" " "	"Peter Beck'r, Belle Plane."	2.42	8.12	3.70	30.04	3	15¼	......	15½	24.5	36.8	74,000	77,600	2,583	
6608	" " "		2.30	8.26	4.05	33.45	3	13¼	1	3¼	31.4	43.2	75,800	75,800	2,266	From O. R. Mather, Pelican Rap's.
6609	Red Brick, hard burnt.		2.30	7.70	3.72	28.64	4	8¼	......	8	11.1	21.	63,000	212,000	7,402	From A. C. Ochs.
6610	Buff col'r Brick	"Ness & Moog, St. Cloud."	2.25	8.26	3.88	32.05	3	11¼	1	......	27.	38.2	95,000	131,000	4,067	
6611	Red Brick.		2.15	7.94	3.83	30.41	3	12¾	......	10¾	17.7	28.4	37,500	40,100	1,311	From J. A. McKay, Alexandria.
6612	" "		2.26	8.05	3.80	30.59	4	14¼	......	10¼	15.	25.6	87,000	90,050	2,944	From M. Mueller, Stillwater.
6613	Dry slate shale Brick, semi-dry.		2.29	8.45	4.07	34.39	5	13¾	......	8	8.5	17.5	238,000	249,200	7,246	From St. Louis River Slate Brick Co.
6614	Alexandria Bld'g. Brick		2.14	7.79	3.82	29.76	3	12½	.....	8¾	14.5	23.7	51,000	62,700	2,107	
6615	Red Brick.		2.16	7.87	3.64	28.65	4	3¼	......	6¾	10.	18.8	158,000	202,100	7,054	From M. Mueller, Stillwater.
6616	Dry slate shale Brick, semi-dry.		2.34	8.49	4.10	34.81	6	¾	......	9	9.3	19.1	202,000	208,500	5,990	From St. Louis River Slate Brick Co.
6617	Red Brick.		2.32	8.09	3.74	30.26	4	8¾	.....	10½	14.4	25.8	45,000	73,900	2,442	From John Lind, Barnum.
6618	" (light)		2.20	7.88	3.83	30.18	4	5¾	.....	10¾	15.4	27.9	132,000	159,900	5,298	From F. X. Goulets, Staples.
6661	Kasota Pink Limestone.		4.82	4.88	4.92	24.01	.....	......	......	......	....	....	174,000	261,300	10,833	From quarries of C. W. Babcock & Co., Mankato, Minn.
6662	Mankato Sandstone.		4.05	4.08	4.11	16.67	.....	......	......	.....	......	....	130,000	161,100	9,606	Tested on edge.
6663	Mantorville Sandstone.		3.96	3.99	4.03	16.08	.....	......	......	......	....	....	141,100	141,100	8,775	
6664	Frontenac Sandstone.		3.96	4.00	3.96	15.84	......	......	......	......	....	....	148,000	160,200	10,114	
6665	Luverne Quartzyte		4.23	4.12	3.93	16.19	......	......	......	......	....	....	349,000	349,000	21,556	
6666	" "		4.22	3.97	4.03	16.00	......	......	......	......	....	......	299,600	318,000	19,875	
6667	Ortonville Granite.		4.03	3.90	4.02	15.68	......	......	......	......	....	....	300,200	320,100	20,415	
6668	Duluth Brownstone		3.98	3.96	4.02	15.92	......	......	......	......	....	....	69,300	69,300	4,353	
6669	Faribault Marble.		4.28	4.29	4.23	18.15	......	...	......	......	....	....	137,000	322,700	17,780	

XI.

LIST OF ROCK SAMPLES COLLECTED IN 1894.

BY U. S. GRANT.

The present list is a continuation of those found in: (1) the 17th Ann. Rept., pp. 201-215; (2) the 20th Ann. Rept., pp. 96-110; (3) the 21st Ann. Rept., pp. 59-67; (4) the 22nd Ann. Rept., pp. 78-86. Most of these rock samples have not been carefully studied in the laboratory, and so the names are to be regarded as often only approximately correct. The specimens in this series are numbered in green and can thus be distinguished from those of any other series of the survey or museum. Most of the specimens listed below are from the vicinity of Carlton or from the Rainy Lake region. Nos. 1058 to 1067 were collected by Mr. H. V. Winchell.

1017. Soft greenish shale, showing banding. North side of the St. Louis river at the mouth of the small creek in S. E. ¼ S. E. ¼ sec. 2, 48 16. This shale underlies unconformably a coarse conglomerate.

1017A. Quartzyte pebble from this conglomerate. Same place.

1017B. Dark flinty pebble. Same place.

1017C. Slate pebble. Same place.

1017D. Reddish melaphyre pebble from conglomerate. North side of the St. Louis river at the mouth of a stream, near center of sec. 1, 48 16.

1018. Gray slate, showing fine laminæ which are not parallel with the bedding. First rock cut on the Northern Pacific R. R. west of Wrenshall; N. W. ¼ N. W. ¼ sec. 8, 48-16.

1019. Fresh diabase from dike. Same place.

1020. Medium grained, pinkish, biotite granite. N. E. ¼ S. E. ¼ sec. 27, 67-13; west end of Bottle portage, Lac la Croix.

1021. Biotite gneiss. N. E. ¼ N. E. ¼ sec. 11, 67-14; southwest side of Roland island, Lac la Croix.

1022. Brownish, biotite schist. N. E. ¼ S. W. ¼ sec. 35, 68-14; end of point, Lac la Croix.

1023. Staurolite, biotite schist. N. E. ¼ N. E. ¼ sec. 34, 68-14; north side of small island, Lac la Croix. Rock not certainly *in situ*, but probably not far from the parent ledge.

1024. Biotite schist. S. E. ¼ S. E. ¼ sec. 33, 70-18; Kettle falls.

1025. Sericitic schist. S. E. ¼ S. W. ¼ sec. 35, 71-24.

1026. Fine grained, micaceous schist. S. W. ¼ S. W. ¼ sec. 33, 71–24; south shore of Rainy river.

1027. Biotite schist. Same place.

1028. Greenish schist. Near center of S. W. ¼ sec. 33, 71-24; reef near south shore of Rainy river.

1029 to 1029E. Series of specimens showing transition from biotite schist to biotite syenite. The more western of the two islands in the Rainy river, about three-fourths of a mile below Koochiching falls.

1030. Biotite hornblende syenite. Ft. Frances, Ontario; from the excavation for the canal.

1030A. Porphyritic facies of the same. S. E. ¼ S. W. ¼ sec. 27, 71-24; south shore of Rainy river.

1030B. Altered diabase from dike in the syenite. Same place.

1031. Diabase from center of dike in syenite. Near center of N. ½ N. W. sec. 35, 71-24; south shore of Rainy river.

1032. Brownish biotite schist. Near center of S. ½ S. W. ¼ sec. 25, 71-24; south shore of Rainy river.

1033. Brownish micaceous schist. 140 paces south of the east quarter post of sec. 25, 71-24.

1033A. Very fine grained, gray schist. Same place.

1033B. Gray siliceous rock. Same place.

1034. Greenish schist. Just south of the east quarter post of sec. 36, 71-24.

1035. Greenish siliceous schist. 550 paces south of the east quarter post of sec. 36, 71-24.

1036. Siliceous schist, rather coarse grained and massive in appearance. N. E. ¼ N. W. ¼ sec. 30, 71-23; south shore of Rainy lake.

1037. Mottled biotite schist. Near center of E. ½ N. W. ¼ sec. 29, 71-23; point on south shore of Rainy lake.

1038. Green schist. S. W. ¼ N. W. ¼ sec. 28, 71-23; south shore of Rainy lake.

1039. Dark, fine grained, micaceous schist. S. W. ¼ N. W. ¼ sec. 28, 71-23; south side of small point, south shore of Rainy lake.

1040. Biotite granite. The smaller of the two islands in the N. W. ¼ sec. 28, 71-2; Rainy lake.

1040A. Contact of mica schist and granite. Same place.

1041. Aplyte from dike. Same place.

1042. Greenish, micaceous schist. N. E. ¼ N. W. ¼ sec. 26, 71-23; Kingston island, Rainy lake.

1043. Greenish schist, matrix of conglomerate. Small island near center of W. ½ S. W. ¼ sec. 26; Jackfish bay, Rainy lake.

1043A. Conglomerate. Same place.

1043B. Gray pebble from the conglomerate. Same place.

1043C. Collection of pebbles from the conglomerate. Same place.

1043D. Fine grained biotite granite pebble in conglomerate. S. W. ¼ S. W. ¼ sec. 26, 71-23; south shore of Jackfish bay, Rainy lake.

1044. Volcanic tuff? South shore of Rainy lake at the west line of sec. 25, 71-23.

1045. Green conglomerate. West shore of small bay near the south line of sec. 30, 71-22; south shore of Rainy lake.

1046. Peculiar graywacke-like rock. S. W. ¼ S. E. ¼ sec. 30, 71-22; south shore of Rainy lake.

1047. Greenish schist. N. W. ¼ N. E. ¼ sec. 32, 71-22; south shore of Rainy lake.

1048. Brownish gray siliceous rock occurring in beds in the mica schist. South shore of Rainy lake, just west of the east line of sec. 32, 71-22.

1049. Green schist. N. E. ¼ N. W. ¼ sec. 33, 71-22; Little American island, Rainy lake.

1049A. Sericitic schist. Same place.

1049B. Darker phase of the same. Same place.

1050. Sericitic schist. S. E. ¼ N. W. ¼ sec. 28, 71-22; north side of Grindstone island, Rainy lake.

1051. Schistose quartz porphyry. Near center of E. ½ S. E. ¼ sec. 26, 71-22; small island in Rainy lake.

1052. Brownish biotite schist. S. E. ¼ N. E. ¼ sec. 36, 71-22; south shore of Rainy lake.

1052A. Micaceous schist. N. E. ¼ N. W. ¼ sec. 36, 71-22; south shore of Rainy lake.

1053. Gray muscovite biotite syenite. S. E. ¼ S. E. ¼ sec. 25, 71-22; south shore of Rainy lake.

1054. Greenish schist containing siderite. Lyle mine, near center of S. E. ¼ sec. 23, 71-22; north side of Dryweed island, Rainy lake.

1054A. Greenish rock laminated by siliceous bands. Same place.

1054B. Quartz and siderite from vein. Same place.

1055. Biotite gneiss, charged with pyrite. S. E. ¼ S. E. ¼ sec. 33, 71-22; Old Soldier mine; small island in mouth of Black bay, Rainy lake.

1055A. A darker phase of the same. Same place.

1056. Pinkish, biotite granite. Probably in N. ½ sec. 35, 65-17; east side of Vermilion river at north end of a long portage.

1057. Gold bearing quartz from vein. Lot 6, sec. 30, 63-12; near Ely.

1028. Greenish conglomerate. AL 76, north side of Shoal lake.

1059. Greenish conglomerate. Shoal lake.

1060. Conglomerate at contact with altered granite. North of Shoal lake.

1061. Greenstone. North shore of Shoal lake.

1062. Contact of saussurite gabbro and granite. Small lake south of Bad Vermilion lake.

1063. Saussurite gabbro. Island bay, Bad Vermilion lake.

1064. Biotite granite. A L 75, Wiegand's land, north of Shoal lake.

1065. Altered granite? Same place.

1066. Another phase of the same. Same place.

1067. Altered granite? Same place.

XII.

NOTES UPON THE BEDDED AND BANDED STRUCTURES OF THE GABBRO AND UPON AN AREA OF TROCTOLYTE.

BY ARTHUR HUGO ELFTMAN.

CONTENTS.

INTRODUCTION.

The following notes are based upon field observations made for the geological survey and subsequent laboratory study of the material collected. The writer has had the opportunity to examine the great gabbro mass of northeastern Minnesota through its entire width from the Duluth and Iron Range railroad to the vicinity of lakes Alice and Bellissima. From the former lake eastward through Little Saganaga lake to the region south of Gunflint lake, only the northern portion of the gabbro was examined by him. As the time, opportunity or necessity afforded, many localities were visited several times.

In the twenty-second annual report (p. 169) attention was called to several localities where interesting observations were made upon the gabbro. It is intended at present to give a short account of the following:

1. The bedded and banded phases of the gabbro.
2. The occurrence of the feldspar masses in the gabbro.
3. The description and relations of a dark, bedded olivine gabbro, or troctolyte.

MACROSCOPIC CHARACTERS AND FIELD RELATIONS.

Under this heading will be given some of the macroscopic characters of the rocks under consideration and their relations and appearance in the field. For a general description of the normal gabbro, the reader is referred to Dr. Bayley's discussion of the basic massive rocks of the Lake Superior region.*

The bedded and banded phases of the gabbro.

In the reports of the Minnesota geological survey frequent reference has been made to the "bedded" character of the normal gabbro in different localities. By this character invariably is meant a rude arrangement of the rock in parallel layers similar to the layers of sedimentary rocks. This is quite a common phenomenon along the northern limits of the great gabbro mass. The layers usually have a dip toward the south and in places this character may be quite extensive. The separation into layers does not depend upon a differentiation of the mineral components of the rocks, for it is usually best developed in a rock of medium texture and of a uniform distribution of the minerals. From this it seems that the peculiar bedded appearance is due to secondary causes acting upon the rock after it had solidified.

Under banded structure the writer includes the laminated appearance of the gabbro, which is due to the differentiation and arrangement in parallel bands of the mineral constituents of the rock. The bands have no regular arrangement. They appear and disappear in a manner not depending upon secondary causes. The gabbro, which usually presents a fairly uniform texture, along its central portion possesses the banded structure to a marked degree.

In considering the differentiation within the gabbro attention will be called to the various stages in which this has been noticed. South of Disappointment lake (T. 63 N., R. 8 W.) a short distance south of the contact with the older rocks the gabbro is medium grained and olivinitic. The "bedded" structure is well developed. In going south from here a distance of two or three miles one passes over ridges of this same gabbro. But away from the northern edge the rock has a tendency to become more varied in structure. The feldspathic and olivinitic portions occur in separate aggregates, giv-

*Journal of Geology, vol. i, Nos. 5, 6 and 7.

ing a peculiar spotted appearance to the rock. The diallage and olivine usually form clusters of crystals arranged radially around a common center. These areas vary in diameter from one to four inches. The plagioclase which makes up the greater part of the rock also fills up the spaces between the diallage and olivine. Although the olivine is altered on the surface to a brownish yellow product, thin sections of the rock show that it is quite fresh within the rock. Occasional boulders show the peculiar structure of the rock by their alteration. Apparently firm and fresh when struck with a hammer, these boulders readily crumple leaving the feldspathic portions in firm nodules and the olivinitic portions as a coarse sand. This disintegration is due to the alteration of the olivine.

The separation of the mineral constituents is quite common in the normal facies of the gabbro, and is mentioned by Dr. Bayley* as follows: "The varieties are merely local phases of the predominant rocks for on all sides they grade into one another by insensible transitions." It is the writer's intention to call attention to the separation into a sharply defined banded structure, which can be easily distinguished from the ordinary differentiation of the rock, which causes only a variation in the amount of the different minerals. This may occur in such proportions that areas of feldspar several yards in diameter may be separated. In the banded structure some of the bands have the composition of the normal gabbro; while others are composed almost wholly of feldspar on the one hand and the iron-bearing minerals on the other. The lines of division between the different bands are usually sharp and distinct, The bands vary in thickness from several inches to several feet and are generally quite irregular, varying considerably in thickness in different parts. There is no general direction in the bands. They are found in all portions and running in every direction. In this they differ from the bedded structure, which has nearly always a dip toward the south.

The banding is similar to that described and illustrated by Geikie and Teall in the Tertiary gabbro in the Isle of Skye.* The gneissic or banded structure is also referred to in Bulletin VI, of the Minnesota survey, p. 126. The hill east of Birch lake, mentioned in Bulletin VI, possesses more of the bedded than the banded structure, although the two are somewhat coincident in this case. The illustration shows the bedded and

*Jour. of Geol., vol. 1, No. 7, p. 698.

*Quar. Jour. Geol. Soc., vol. iv, No. 200, p. 645.

not the banded structure. The importance of this banded structure is best considered in connection with the large feldspar masses within the gabbro.

The occurrence of the feldspar masses in the gabbro.

The large areas of feldspar rock south of Little Saganaga lake and westward along the central part of the gabbro area have been mentioned in the Minnesota reports.* These feldspar masses have been found in sizes varying from an aggregate of several crystals to mountain masses. The different areas have the same relation to the normal gabbro, and are of the same origin.

In the southeastern part of T. 61 N., R. 11 W. of the Fourth principal meridian, the gabbro possesses a marked banding. The feldspar bands often are ten to fifteen feet wide and occasionally widen out and form lenticular or oval areas of even greater width. The banding is continuous and the direction is parallel to the outlines of the feldspar masses. The composition of the bands was mentioned on a preceding page. That the smaller areas are due to the differentiation of the gabbro cannot be doubted, for their occurrence does not depend upon the banded structure of the gabbro. The line of division between the feldspar masses and the normal rock is sharp and distinct in the field and in hand specimens. This suggests that they may be inclusions of some older rock in the gabbro. Microscopical characters, however, show that this is not the case.

On account of their greater hardness the feldspar masses usually occur in knobs rising above the ordinary gabbro. Occasionally along the side of some perpendicular bluff the outlines of the rounded feldspar masses, surrounded on all sides by ordinary gabbro, can be made out. In section 36, T. 61 N., R. 11 W., a dome-shaped mass of feldspar, surrounded on all sides by the ordinary gabbro, rises fifty feet above the surrounding rock. On the southern flank of the mass and near the top are some patches of gabbro showing that the present and the original size of the mass are nearly the same.

In the large valley in the southeastern part of T. 61 N., R. 10 W., are extensive low outcrops of the feldspar rock. This rock is not found in contact with the ordinary gabbro, but a short distance south of the most southerly outcrop, a dome-shaped hill of ordinary gabbro rises several hundred feet

*Bulletin VI, p. 123. 22nd Ann. Rep., p. 169.

above the valley. Although it may appear that the two rocks in this locality are distinctly separate, there is no reason why their relations are not the same as at the last locality.

The high ridges south of Gabbro lake in T. 62 N., R. 10 W., also show various sized areas of feldspar in the predominating ordinary gabbro. The banded structure appears to some extent in connection with the feldspar.

An area of bedded and banded olivine gabbro.

In the southern part of T. 62 N., R. 10 W., the eastern part of T. 61 N., R. 11 W., the greater part of T. 61 N., R. 10 W., and extending into the townships south and east of the last named, is a considerable area of a dark, often reddish colored gabbro. On account of the small proportion of feldspar the color depends upon the character of the olivine. When fresh the rock has a dark waxy appearance, and when altered the color is usually dull black to brownish red or reddish yellow. A banded arrangement of the minerals is quite common, while the bedded structure prevails throughout the rock. The bedding does not depend upon the banding, for it has a comparatively uniform dip to the south and the bedding planes often are perpendicular to the banded structure.

The relation of this rock to the normal gabbro and the feldspar rock are somewhat difficult to determine. It has not been found in direct contact with them, since in every locality observed by the writer the contact was covered. The results of these observations may be stated as follows: Wherever the dark bedded olivine rock and the gabbro approach each other, even within a few feet, both preserve their characteristic structure and there are no signs of a transition of the one into the other. The olivine rock appears to be above the gabbro. It does not occur in a continuous area but there are several detached areas on the northeast shore of Bald Eagle lake, T. 62 N., R. 10 W., and in section 30, of the same township. At the last named locality the olivine rock is separated from the main mass by several ridges of ordinary gabbro.

MICROSCOPIC CHARACTERS.

The banded gabbro.

The mineral constituents are the same as those of the normal gabbro. The microscopical examination of the contact between the different bands will be of most interest. The texture of the different bands is the same and the minerals of one band

are intimately united with those of the adjacent bands, showing that the bands were solidified at the same time and that the separation into layers is due to the differentiation of mineral constituents at the time of cooling.

The feldspar masses.

In thin sections these are seen to be composed of plagioclase feldspar, which, on the whole, probably possesses a higher extinction angle than is usually found in the feldspar of the normal gabbro. Occasional grains of olivine and diallage occur. The rock is quite fresh and the feldspar crystals are often perfectly clear and colorless. An examination of the contact with the normal gabbro shows the same results as given above, for the banded gabbros.

The dark banded olivine gabbro.

Just as this rock is distinctly separable from the normal gabbro in the field, so its microscopical characters are also different. The rock is composed of plagioclase and olivine with small grains of diallage and magnetite. The olivine makes up the greater part of the rock. It occurs in fairly regular crystal forms and is quite fresh. It is frequently altered to serpentine along numerous fractures through the grain. When alteration has gone on to a great extent, besides the serpentine, a brownish red product is formed staining the whole rock and giving it a brick red appearance. In nearly all cases the olivine is filled with numerous grains of magnetite, often making the mineral opaque.

The feldspar is a plagioclase, is quite fresh and is the same as that in the normal gabbro. It possesses, however, a shattering peculiar to this area in the Minnesota gabbro. Although fresh, the mineral is traversed by numerous fracture lines which are arranged radially around the olivine grains The degree of shattering does not depend upon the condition of the olivine, for it is just as prominent in the fresh rock as it is in the altered portions. In the altered specimens the alteration products of the olivine sometimes penetrate the fractures. The pyroxene when present is associated with the olivine.

The rock is properly a forellenstein or troctolyte. A section of troctolyte from Neurode in Silesia, which shows the same peculiar shattering of the feldspar, might easily be mistaken for a section of the rock representing the area described above. A section of this troctolyte from near Duluth was described by

Dr. Wadsworth.* The field relations of this rock are the same as those given for the area just described.† The hand specimens and thin sections of the rocks from these localities correspond in all their characters.

The troctolyte differs from the normal olivine gabbro in that in the former the pyroxene is present only in occasional grains, while in the latter, although it may be absent in a few sections. it is usually present in sufficient quantity to change the character of the rock. The olivine is the predominating component of the troctolyte and not of the olivine gabbro. The feldspar in the former is always thoroughly shattered and the fractures are arranged radially around the olivine. In the olivine gabbro, no matter how altered the olivine may be, the feldspar, beyond a few fractures, shows no shattering similar to that in the troctolyte. It may be of interest to notice that a large bowlder of this troctolyte has been found imbedded in the diabase at Beaver Bay and having the same relations to the matrix rock as the anothosyte.

SUMMARY.

In the preceding note the writer has attempted to emphasize the necessity of distinguishing between the bedded and banded structures of the Minnesota gabbro. As the term "bedded" implies a sedimentary origin of the rock, there is some objection in applying it to a structure in an eruptive rock. The terms bedded and banded are often used as synonyms, but it has been shown that in the Minnesota gabbro there exist two distinct structures which are different in origin. As a more appropriate term for what has been called "bedded" structure the writer proposes the term *sheeted.* This structure is very common in nearly all of the igneous rocks of Minnesota. Attention is called to the occurrence and formation of the large feldspar masses within the gabbro. These masses are regarded as parts of the gabbro itself and as due to a differentiation of that rock. The area of troctolyte is outlined, and some of the distinguishing features of the rock are given. Although this area may be a part of the great gabbro mass, it is necessary to note its relation to the gabbro as well as its peculiar microscopical characters.

*Bull. No. II, p. 95, No. 514, and plate V.

† 10th Ann. Rep't., 1881, p. 35, No. 514.

XIII.

ADDITIONS TO THE LIBRARY SINCE THE REPORT FOR 1893.

The present list consists of additions made from April 1, 1894, to Dec. 31, 1894.

A

Amsterdam. Verhandelingen d. K. Akad. v. Wetenschappen, vol. iii, Nos. 1-14, 1894.
  Verslagen d. Zittengen, May, 1893, to April, 1894.
Augsberg. Bericht Naturw. Vereins f. Schwaben und Newburg, vol. xxxiv, 1891-93.

B

Baltimore. Amer. Chem. Jour., xvi, 3-8, 1894.
  Johns Hopkins Univ. Circulars, xiii, 111-114; xiv, 115, 1894.
Basel. Verhandl. Naturforsch. Gesellsch., ix, 3, 1893.
Berkeley. Bull. Dept. Geology, Univ. of Calif., vol. i, Nos. 5-7, Aug. and Oct., 1894.
Berlin. Zeitsch. d. Deutschen geol. Gesellsch., xlv, 3-4, 1893; xlvi, 1, 1894.
  Verhandl. Gesellsch. für Erdkunde, xx, 10, 1893; xxi, 1-8, 1894; Zeitsch., xxviii, 6; xxix, 1-4, 1894.
  Mittheil. Konigl. d. Wissenschaften, ii-viii, 1894.
Bern. Mittheil. Naturforsch. Gesell., Nos. 1305-1334, 1893.
Bonn. Verhandl. Naturh. Vereines der Rheinlande, etc., 1874-1877, 1878-1881, 1882-1883.
Boston. Proc. Amer. Acad. Science and Arts, w. s. xxviii, n. s. xx, 1892-1893; w. s. xxix, n. s. xxi, 1893-1894.
  Proc. Boston Soc. Nat. History, xxvi, 2-3, 1893-94.
Brunn. Verhandl. Naturforsch. Vereines, xxxi, 1892.
  Berichte Meteorol. Commission, xi, 1891.
Budapest. Földtani Közlöny Ungarisch. Geologisch. Gesellsch., xxiii, 11-18, 1893; xxiv, 1-8, 1894.

C

Cambridge. Harvard College, Mus. Comp. Zool., Bull. vol. xxv, Nos. 7-11, 1894.
Carrieroes. Annaes d. Sciencias Naturaes, i, Nos. 1-4, 1894.
Chapel Hill. Jour. Elisha Mitchell Sci. Soc., x, 2, 1893.
Chicago. Journ. of Geology, ii, 3-8, 1894.
Christiana. Report Norske Nordhafs Expedition, xxii, 1893.
  Beskrivelse af en raeke Norske Bergarter, Dr. Th. Kjerulf, 1892.
Cincinnati. Journ. Cincinnati Soc. Nat. Hist , xvii, 1-3, 1894.

D

Darmstadt. Natizblatt zu Vereins für Erdkunde, iv, No. 14, 1893; Abhandl. zu Vereins für Erdkunde, ii, No. 3, 1894.

Denver. Colorado Sci. Soc., Extr. from Proc., 1894.

Des Moines. Annual Rept. Iowa Geol. Surv., vol. ii, 1894.

Dublin. Sci. Proc. Roy. Dublin Soc., n. s. vii, 5, 1891-92; n. s. viii, 1-2, 1893-94; Sci. Trans. Roy. Dublin Soc., ser. 2, iv, 14, 1892; ser. 2, v, 1-4, 1893.

E

Edinburgh. Trans. Edinburgh Geol. Soc., vi, 5, 1893.

Erlangen. Sitzungsb. Phys.-med. Societat, xxv, 1893.

F

Frankfort. Tenth Ann. Rept. of the Inspector of Mines in Kentucky, 1893.

Frankfort, A. M. Abhandl. Senckenb. Naturf. Gesellsch., xiii; xiv, (1-3); xv, (1-3); xvi; xvii (1-2); xviii (1-3), 1888; Bericht, 1874-1894; five separate volumes.

G

Good Hope. American Antiquarian, xvi, 3-6, 1894.

Göttingen. Nach. Konigl. Gesellsch. d. Wissensch., 14-21, 1893; 1-3, 1894.

H

Halifax. Proc. & Trans. Nova Scotian Inst. Nat. Sci., ser. 2, vol. i, No. 3, 1892-1893.

Hanover. Jahresb. Naturhistorish. Gesellsch., xli-xliii, 1892-1893.

Houghton. Report on Mining School, M. E. Wadsworth, 1893.

K

Kiel. University, 81 pamphlets, mostly inaugural dissertations.

Konigsberg. Schriften Phys.-okonomisch. Gesellsch., xxxiv (in duplicate).

L

Lawrence. Kansas University Quarterly, vol. i, 1892; vol. ii, 1893; vol. iii, 1894.

Leige. Annales Soc. Géol. d. Belgique, xx, 1892-93; xxi, 1893-94.

Leipzig. Berichte Kongl. Säch. Gesellsch. d. Wissensch., vi-ix, math.-phys. Classe, 1893; i, math.-phys. Classe, 1894.

Mittheil. Vereins f. Erdkunde, 1893.

Lund. Ars-skrift Lunds Universitets, xxix, 1892-1893.

M

Marburg. Sitzungsb. Gesellsch. z. Beford. Naturwissensch., 1893.

Metz. Jahresb. Vereins f. Erdkunde, xvi, 1893-94.

Mexico. Memorias y Revista Sociedad Cientifica "Antonio Alzate," vii, Nos. 7-12, 1893-94.

Minneapolis. American Geologist, xiii, 4-6; xiv, 1-6, 1894.

Occasional Papers, Minn. Acad. Nat. Sciences, i, No. 1, 1894.

Montevideo. Anales Museo del Nacional, i, No. 1, 1894.

Moscow. Bull. Soc. Imp. d. Naturalistes, ii, No. 1, 1894.

München. Bayerisches Industrie u. Gewerbeblatt, xxvi, Nos. 7-51, 1894.

N

Neuchatel. Bull. Soc. d. Sci. Naturelles, xvii-xx, 1889-1892.
New Haven. Trans. Connecticut Acad. Arts and Sciences, ix, No. 1, 1892.
New York. Bull. Amer. Geog. Soc., xxv, pt. 2; xxvi, pts. 1-3, 1893-1894.
Ann. Rept. Trustees Am. Mus. Nat. Hist., 1892-93.
Trans. N. Y. Acad. Sci., xiii, 1893-94.
Nurnberg. Abhandl. Naturhistorisch. Gesellsch., x, No. 2, 1893.

P

Paris. Bull. Soc. d. Sci., Nat. d. l'Ouest d. l. France, iii, No. 4, 1893; iv, No. 1, 1894.
Comptes Rendus Soc. d. Geog., Nos. 1-15, 1894; Bull. xvi, 1894.
Bull. Soc. Zool. d. France, xvii, No. 9, 1893; Mémoires, vi, Nos. 1-4, 1893.
Philadelphia. Proc. Acad. Nat. Sciences, ser. 3, xxiii, pt. 3, 1893; ser. 3, xxiv, pts. 1-2, 1894.
American Naturalist, xxviii, Apr.-Dec., 1894.
Prag. Sitzungsb. (math.-naturw. Classe) Gesellsch. d. Wissensch., 1892-1893; Jahresb., 1892-1893.

S

Sacramento. Bull. Calif. State Mining Bureau, iii, 1894.
San Francisco. Proc. Calif. Acad. Sciences, 2nd ser., iv, No. 1, 1894.
San Jose. Annales Inst. Fisico-geog., iv, 1891.
Santiago. Actes Soc. Sci. d. Chili, iii, Nos. 3-5; iv, Nos. 1-2, 1894.
Sao Paulo. Boletin Com. Geog. e. Geol., 8-11, 1889-1892.
State College. Mining Bull. Pa. State College, i, Nos. 1-2, 1894.
Stavenger. Aarsberetning Stavanger Museum, 1892.
St. Louis. Trans. Acad. Science, vi, Nos. 12-16, 1894.
Ann. Rept. Missouri Botanical Garden, 1894.
Stockholm. Förhandl. Geol. Fören., xvi, Nos. 2, 4, 5, 1893.
Handl. K. Svenska Vetens.-Akad., xix, No. 2-4, 1893.
From Geol. Fören. Förhandl., Bd. 16, Nos. 157-159, 1893-94; Systematisch förteckning etc., 1862-1893.
St. Petersburg. Verhandl. Russisch-kaiserl. mineral. Gesellsch., xxx, 1893.

T

Tufts College. College Studies, i-iii, 1894.

U

Upsala. Sonder-Abdruck aus Bull. Geol. Institute, i, No. 2, 1893.
Arsskrift Upsala Universitet, 1893; Inaugural dissertation, 1894.

V

Vienna. Annalen K. K. Naturhistorisch. Hofmuseums, viii, Nos. 3-4, 1893; ix, Nos. 1-2, 1894.
Verhandl. K. K. Zool.-Botan. Gesellsch., xliii, Nos. 3-4, 1893; xliv, Nos. 1-2, 1894.

W

Washington. U. S. Geol. Survey, Ann. Rept., xii, pts. 1-2, 1890-1891; xiii, pts. 1-3, 1891-1892. Bulletins, 97-117, 1893-94; Mineral Resources, ix-x, 1892-1893; Monographs, xix, xxi-xxii, 1893.
U. S. Army, Ann. Rept. Chief of Engineers, pts. 1-6, 1893.
U. S. Nat'l Museum, Bulletin No. 43, 1893; Proc. U. S. Nat'l Museum, vol. xvii, Nos. 976-1009, 1894.
Smithsonian Report, 1892.

MUSEUM ADDITIONS

SPECIMENS REGISTERED IN THE GENERAL

Serial No.	Obtained. When.	Obtained. Whence.	Name.	Number of specimens.
8034	1894	Donation.......	Asbestos and country rock......	1
8035	Nov., 1894	Fell Apr. 9, 1894	Chondritic meteorite (Minnesota No. 1)....	3
8036	Dec., 1894	Wm. H. Hobbs.	Coarse ash......	
8037	" "	" "	Fine ash..	
8038	" "	" "	Fragment of olivine bomb....	2
8039	" "	" "	Melilite basalt	2
8040	" "	" "	Nepheline basalt and tachylyte............	1
8041	" "	" "	Pseudobrookite in nephelinyte.............	1
8042	" "	" "	Diabase showing spheroidal weathering ..	1
8043	" "	" "	Trap dike in gneiss...........................	1
8044	" "	" "	Enstatite rock.	1
8045	" "	" "	Stretched dioryte, "cross gashed"..........	1
8046	" "	" "	Schistose porphyry.......	1
8047	" "	" "	Hornblende gneiss; sheared diabase.......	1
8048	" "	" "	Cortlandtyte (hornblende picryte).	1
8049	" "	" "	Spotted gabbro dioryte........................	1
8050	" "	" "	Schistose gabbro dioryte(hornblendegneiss)	1
8051	" "	" "	Allanite granite...............	1
8052	" "	" "	Hornblende norryte (dioryte)...............	1
8053	" "	" "	Hornblende noryte.	1
8054	" "	" "	Mica dioryte................	1
8055	" "	" "	Staurolite-cyanite mica schist............	1
8056	" "	" "	Sillimanite garnet rock...	1
8057	" "	" "	Staurolite-repidolite inclusion............	1
8058	" "	" "	Staurolite-biotite schist.....................	1
8059	" "	" "	Staurolite schist.............................	1
8060	" "	" "	Mica schist..	1
8061	" "	" "	Inclusion, containing emery. in dioryte...	1
8062	" "	" "	" " spinel " " ...	1
8063	" "	Rev. J S Hanner	Clay concretions..............................	8

MUSEUM ADDITIONS

SPECIMENS REGISTERED IN THE GENERAL

Serial No.	Obtained. When.	Obtained. Whence.	Name.	Number of specimens.
8629	May, 1894	By exchange...	Chænocardium ? sp.?.........................	6
8630	" "	" " ...	Orthis striatula, Schlotheim...............	9
8631	" "	" " ...	Atrypa reticularis, Linn....................	7
8632	" "	" "	" "	3
8633	" "	" " ...	" gregeri, Rowley....................	4
8634	" "	" " ...	Spirifera annæ, Swallow	8
8635	" "	" " ...	" euruteines. Owen.................	3
8636	" "	" " ...	Strophodonta callawayensis, Swallow.....	4
8637	" "	" " ...	" altidorsata, Swallow........	8
8638	" "	" " . .	" navalis. Swallow............	8
8639	" "	" " ...	" inflexa, Swallow............	8
8640	" "	" " ...	Naticopsis ? sp.?.........	8
8641	" "	" " ...	Zaphrentis ? sp.?	8
8645	" "	" " ...	Coral...........	1
8646	1894	Presented......	Illænus americanus. Billings...............	4
8647	"	"	Cast of Lamellibranch........................	1
8648	Aug., 1894	By exchange...	Eridophyllum simcoense....................	1
8649	" "	" " . .	Spirifera parryana	4
8650	" "	" " ...	Favosites gothlandica...........	3

MINERALOGY AND LITHOLOGY.

MUSEUM SINCE THE LAST REPORT.

LOCALITY.	Formation.	COLLECTOR AND REMARKS.
Belleview, Redwood Co.	Archean	[weight 9½ lbs.
Polk Co., Minn		Henry Sweet. Largest piece is entire,
Volcano, Lipari Islands		Eruption of 1888. By exchange
" " "		" " "
Alban Hills, Rome, Italy		"
Capo di Bove, " "		"
Rossberg, Hesse		"
Katzenbuchel, near Heidelberg, Ger		"
Brighton, Mass		N. side of Cambridge St. "
Monson, Mass		"
Pelham, Mass		"
Lower Quinnesec Falls, Mich		Figured in Bull. 62, U. S. G. S. "
Upper Quinnesec Falls, Wis		Credner's porphyroid. "
Lower Quinnesec Falls, Wis		See Bull. 62, U. S. G. S. "
Ilchester, Md		J. Hopkins Univ. Cir., No. 65. "
" "		"
" "		[intergrowth.
Ellicott City, Md		Envelope sphenes, allanite-epidote "
Butler's Station, N. Y.		Near Munger's Corners. "
Near King's Ferry, N. Y.		Railroad W. of King's Ferry. "
Stony Point, N. Y.		Dike, on the R. R. near road bridge. "
		[On S. wall of clay pit.
Cruger's Station, N. Y.		Sec. II, near No. 37 (of Pl. I, Fig. 4.) "
		[nite. Contact in Sec. I.
" "		Contains biotite, staurolite, cya- "
		[granite, Sec. III, at top of hill.
" "		Inclusion (Group III) in soda "
		[contact.
" "		Sec. II, midway from road at O to "
		[toward contact in Sec. II.
" "		Garnet & tourmaline, 100 from 250 "
" "		No. 25, Sec. II, loc. O. "
" "		Group I. "
" "		Margarite. Group IV.
		[mi. w. of Willow River.
Willow River, Pine Co., Minn	Drift	Presented. Farm of John Thurnblad, 4

PALEONTOLOGY.

MUSEUM SINCE THE LAST REPORT.

LOCALITY.	Formation.	COLLECTOR AND REMARKS.
Callaway Co., Mo	Snyder creek shales (Hamilton.)	D. K. Greger.
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	" About ½ grown.
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
" "	"	"
Old Concord, Minn	Galena	A. D. Meeds.
" "	"	"
Cobbleskill, N. Y.	Up. Held'b	W. E. Crane.
Belfast, N. Y.	Chemung	"
Erie Co., N. Y.	Hamilton	"

MUSEUM ADDITIONS

SPECIMENS REGISTERED IN THE GENERAL

Serial No.	Obtained. When.	Obtained. Whence.	Name.	Number of specimens.
8651	Aug., 1894.	By exchange...	Cystiphyllum corrugatum	3
8652	" "	" " ...	" varians	3
8653	" "	" " ...	Leiorhynchus limitaris	Several.
8654	" "	" " ...	Athyris spiriferoides	4
8655	" "	" " ...	Spirifera medialis	2
8656	" "	" " ...	Platistoma lineatum	2
8657	" "	" " ...	Nucleospira concinna	3
8658	" "	" " ...	Orthis vanuxemi	3
8659	" "	" " ...	Atrypa aspera	5
8660	" "	" " ...	Tropidoleptus carinatus	5
8661	" "	" " ...	Head of Phacops bufo	2
8662	" "	" " ...	Cystiphyllum conifollis	2
8663	" "	" " ...	Atrypa reticularis	5
8664	" "	" " ...	Spirifera ziczac	2
8665	" "	" " ...	Leiorhynchus mesacostale	4
8666	" "	" " ...	Zaphrentis ampla (= prolifica)	3
8667	" "	" " ...	Streptelasma rectum	4
8668	" "	" " ...	Striatopora limbata	5
8669	" "	" " ...	Favosites goodwyni	5
8670	" "	" " ...	Spirifera hungerfordi	5
8671	" "	" " ...	" mucronata	4
8672	" "	" " ...	" orestes	5
8673	" "	" " ...	Cyantophyllum juvenis	4
8674	" "	" " ...	Rhynchonella eximia	4
8675	" "	" " ...	Favosites digitatus	3
8676	" "	" " ...	Rhynchonella horsfordi	4
8677	" "	" " ...	Strophodonta nacrea	3
8678	" "	" " ...	" arcuata	3
8679	" "	" " ...	Orthis biforata var. lynx	3
8680	" "	" " ...	Rhynchonella capax	5
8681	" "	" " ...	Monticulipora ramosa	3
8682	" "	" " ...	Leptæna sericea	3
8683	" "	" " ...	Stellipora ahtheloidea	4
8684	" "	" " ...	Strephomena alternata	2
8685	" "	" " ...	Orthis testudinaria	2
8686	" "	" " ...	Rhynchonella capax var.?	5
8687	" "	" " ...	Orthis biforata	5
8688	" "	" " ...	" lynx	4
8689	" "	" " ...	" occidentalis	3
8690	" "	" " ...	Terebratula harlani	4
8691	" "	" " ...	Ostrea larva	4
8692	" "	" " ...	Rhynchonella neglecta	4
8693	" "	" " ...	Orthoceras undulatum	1
8694	" "	" " ...	Strophomena corrugata	4
8695	" "	" " ...	Leptocœlia hemispherica	Several
8696	" "	" " ...	Favosites niagarensis	1
8697	" "	" " ...	Orthis hybrida	3
8698	" "	" " ...	Dalmanites limulurus	6
8699	" "	" " ...	Spirifera crispa	2
8700	" "	" " ...	Cœlospira disparilis	4
8701	" "	" " ...	Strophomena depressa	2
8702	" "	" " ...	Leptæna transversalis	5
8703	" "	" " ...	Ceramopora imbricata	2
8704	" "	" " ...	Streptelasma calicula	6
8705	" "	" " ...	Favosites constrictum	6
8706	" "	" " ...	Orthis elegantula	5
8707	" "	" " ...	" hybrida	5
8708	" "	" " ...	Cyclonema cancellatum	4
8709	" "	" " ...	Stephanocrinus gemmiformis	2
8710	" "	" " ...	Strophomena striata	3
8711	" "	" " ...	Pentamerus oblongus	2
8712	" "	" " ...	Graptolithus clintonensis	Several
8713	" "	" " ...	Lingula cuneata	"
8714	" "	" " ...	Leptæna sericea	"
8715	" "	" " ...	Pentremites gordoni	3
8716	" "	" " ...	Chonetes illinoisensis	2
8717	" "	" " ...	Athyris subtilita	5
8718	" "	" " ...	Exogyra arietina	5
8719	" "	" " ...	Belemnites mucronata	4
8720	" "	" " ...	Favosites arbuscula	5
8721	" "	" " ...	Pleurotomaria subcomarginata	3
8722	" "	" " ...	Cyrtina hamiltonensis	4

PALEONTOLOGY.

MUSEUM SINCE THE LAST REPORT.

LOCALITY.	Formation.	COLLECTOR AND REMARKS.
Erie Co., N. Y	Hamilton	W. E. Crane.
York, N. Y	"	"
N. Y	Marcellus shale	"
Moscow, N. Y	Hamilton	"
Moscow, N. Y	"	"
York, N. Y	"	"
" "	"	"
Moscow, N. Y	"	"
" "	"	"
" "	"	"
" "	"	"
York, N. Y	"	"
Moscow, N. Y	"	"
" "	"	"
Belfast, N. Y	Chemung	"
York, N. Y	Hamilton	"
" "	"	"
Moscow, N. Y	"	"
Charleston, Ind	Up. Held'b	"
Rockford, Ia	Hamilton	"
Thedford, Ont	"	"
Rockford, Ia	"	"
Charleston, Ind	"	"
Belfast, N. Y	Chemung	"
Charleston, Ind	Up. Held'b	"
York, N. Y	Hamilton	"
Thedford, Ont	"	"
Rockford, Ia	"	"
Lebanon, Ky	Hudson R	"
Chattanooga, Tenn	Trenton	"
Cincinnati, O	Cincin	"
" "	"	"
Dalafield, Wis	Trenton	"
Nashville, Tenn	Hudson R	"
Curdyville, Ky	Cincin	"
Nashville, Tenn	"	"
Cincinnati, O	"	"
Nashville, Tenn	Hudson R	"
Lebanon, Ky	"	"
New Egypt, N. J	Cretaceous	"
Marlboro, N. J	"	"
Rochester, N. Y	Niagara	"
" "	"	"
" "	Clinton	"
" "	"	"
Racine, Wis	Niagara	"
Rochester, N. Y	"	"
" "	"	"
Therold, Ont	"	"
Rochester, N. Y	"	"
" "	"	"
" "	"	"
Therold, Ont	"	"
Rochester, N. Y	"	"
" "	"	"
" "	"	"
Therold, Ont	"	"
Rochester, N. Y	Clinton	"
" "	Niagara	"
" "	"	"
" "	"	"
" "	Clinton	"
Medina, N. Y	Medina	"
Rochester, N. Y	Clinton	"
Flag Pond, Va	Burlington	"
Youngstown, O	Waverly	"
La Salle, Ill	Coal M	"
Helotes, Tex	Cretac	"
Marlboro, N. J	"	"
York, N. Y	Hamilton	"
Pratts Falls, N. Y	"	"
York, N. Y	"	"

XV.

LIST OF ROCK SAMPLES COLLECTED IN 1894 TO ILLUSTRATE THE FIELD NOTES OF N. H. WINCHELL.

1969. At Barnum, Carlton county, a low ridge west of the railroad station, showing a cut of 3 ft. by the R. R., is in Keewatin fine slate, becoming coarse and approaching fine graywacke. The dip is about 10 deg. toward the south, but the face of the cut shows many minor undulations. The specimen exhibits the finer-grained portions, with many diverse markings and wrinklings in the shining surface.

1970. Coarser and siliceous gray portions of the same outcrop at Barnum. There are in this rock siliceous masses and some white quartz in cavities.

1971. Micaceous fine graywacke. Moose Lake, Carlton Co.

1792. Center of sec. 16, 46-20, on Kettle river, Carlton Co. Samples of the supposed gold ore, for which mining operations were conducted at the mouth of Otter creek by Cunningham and Miner a few years since. The rock is a compact sericitic schist and the yellow ore is pyrite, disseminated through the cleavages of the rock itself in formless films and sheets, and occurring with quartz and siderite in cavities.

1973. Sample of red Keweenawan conglomerate furnished by Mr. S. J. Basye, Moose Lake, Carlton county. This is said by him to occur in a small outcrop, mainly under water, in a ravine, sec. 30, T. 46-18. He also states that in a low bluff it occurs further east. This place has not yet been seen by any party of the survey. If this report be authenticated, and the rock be found to be *in situ*, it will fix an important geographic datum for mapping the Keweenawan.

1974. S. E. ¼ S. E. ¼ sec. 2, 48-16. Sample of the soft green Keewatin rock, underlying the conglomerate at the river, from

the point of contact. The Keewatin here has a plain low angle of sedimentary dip toward the south (say 20 deg.). If properly treated it would apparently make slate pencils.

1975. Sample of the finer sedimentary gritty material interstratified in the overlying quartzose conglomerate at the same place as the last.

1976. Pebbles from the crumbling red conglomerate which overlies the Keewatin and the quartzose conglomerate, at the mouth of the creek entering the St. Louis river on S. W. ¼ sec. 1, 48-16. These pebbles seem to show that this conglomerate is later in date than the traps, amygdaloids and porphyries of the Keweenawan—i. e. this part of it. But some of the pebbles are not from the Keweenawan; a very few are from the Keewatin, some may have come from the Animikie, and one is a piece of iron pyrite which embraces rounded grains of quartz, quite similar to the pyrite found in such abundance in the underlying quartzose conglomerate which itself contains no Keweenawan pebbles. Such a piece of pyrite has no known source except from the pyrite-bearing quartzose conglomerate which appears in the valley a short distance higher up the St. Louis. The strong contrast in the pebbles from these two conglomerates, and especially the occurrence of this pebble of pyrite in the upper one, points to the existence of two conglomerates in this valley, one of which would be in that case of the age of the Pewabic, at the base of the Animikie, and the other post-Keweenawan. There are, however, some large pebbles of coarse grit, with scattered kaolinic grains, in the lower conglomerate which may have come from the Pewabic, though not necessarily so. There are also a few large pebbles of hardened black slate which appear like the black slate of the Animikie hardened by the gabbro of Duluth. These latter facts seem to link the conglomerates together as of one date, post-Keweenawan. Yet this grit and this fine-grained black rock can be referred directly to their source in the Keewatin (see for instance Nos. 469, 458 and 468). No structural facts were observed indicating two dates for the accumulation of this conglomerate. In the 10th report (pp. 11, 32-34) are references to this conglomerate. The calcite vein, mentioned on p. 11, as well as the compact and hardened condition of this quartzose conglomerate, and its abundant pyrite, indicate an age greater than post-Keweenawan. The fact also, mentioned in the 10th report, p. 34, that the slaty structure of the underlying Keewatin produces a roughly similar slaty disintegra-

tion extending for some distance upward into the conglomerate, rather points to the production of the slatiness since the formation of the conglomerate. That would exclude it from being of post-Keweenawan age.

1977. Sample of fresh dike-rock, from the R. R. cut, N. W. ¼ S. W. ¼, sec. 8, 48-16, Carlton county. The dike cuts the slates of the region.

1978. Samples of slate, from the same R. R. cut, showing an incipient secondary cleavage.

1979. Sample of slate, from the same R. R. cut, showing a curiously crumpled fine banding, which seems not to be a sedimentary banding but a secondary structure due to the irregularity of the fiber, the latter perhaps caused by dynamic pressure. There is a fine opportunity presented in these rocks for the study of the structures produced in fragmental rocks by pressure. The ordinary slaty cleavage is but one of the results of such action.

INDEX.

A

C

D

E

F

G

H

J

K

L

Q

R

S

T

U

V

W